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CIVIL EFFECTS STUDY

EXPERIMENTAL EVALUATION OF THE FALLOUT-RADIATION PROTECTION PROVIDED BY SELECTED STRUCTURES IN THE LOS ANGELES AREA

Z. G. Burson

Issuance Date: February 26, 1963

CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

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PRINTED IN USA
Price $2.25. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

USAEC Division of Technical Information Extension, Oak Ridge, Tennessee

EXPERIMENTAL EVALUATION OF THE FALLOUT-RADIATION PROTECTION PROVIDED BY SELECTED STRUCTURES IN THE LOS ANGELES AREA

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June 1962

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ABSTRACT

An experimental study designed to provide a basis for estimating protection against fallout radiation was conducted on four diversified structures in the Los Angeles, Calif., area. This study was sponsored by the Civil Effects Test Operations (CETO), Division of Biology and Medicine, U. S. Atomic Energy Commission. The four buildings studied were (1) the Laboratory of Nuclear Medicine and Radiation Biology at the University of California at Los Angeles (UCLA); (2) a family fallout shelter; (3) the communications section of the Los Angeles Police Department building; and (4) a typical classroom located at North Hollywood High School.

A fallout radiation field was simulated by the Mobile Radiological Measuring Unit. The unit employed a single radioactive Co^{60} source, which was pumped at a uniform speed through a long length of tubing evenly distributed over the area of interest. Measurements of the radiation levels at selected points inside the structures were made with highly sensitive ionization-chamber detectors. Protection factors ranged from 10 to 2000 in the UCLA building, up to 10,000 in the family fallout shelter, from 50 to 150 in the communications section of the police building, and from less than 10 to approximately 20 in the high school classroom.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to all the technical participants whose efforts made possible the successful completion of the project. The author also gratefully acknowledges the many valuable contributions made by each of the following:

1. R. L. Corsbie and members of the Civil Effects Test Operations staff for their over-all support.
2. Dr. J. F. Ross, L. B. Silverman, and other staff members of the Laboratory of Nuclear Medicine and Radiation Biology at the University of California at Los Angeles for their excellent support during the measurements at their structure.
3. J. M. Quinn, W. Frank, and E. C. Folger of the Los Angeles Office of Civil Defense for their coordination of the civil defense aspects of the program.
4. Chief W. R. Parker and his staff, particularly J. H. Kinsling, of the Los Angeles Police Department for their excellent support during the measurements at their building.
5. Mr. and Mrs. Jay Gould III and their family for their cooperation in the use of their home and fallout shelter for one of the tests.
6. J. C. Rogers, R. Miller, and B. Ault of the Los Angeles City Health Department for their assistance in planning and executing some of the radiological safety procedures.
7. Dr. A. W. Bellamy, Consultant, Division of Biology and Medicine, U. S. Atomic Energy Commission, for his many helpful suggestions and coordination throughout the course of the project.
8. J. Paris of Edgerton, Germeshausen & Grier, Inc., for his assistance in editing and preparing the report.

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Chapter 1

INTRODUCTION

1.1 GENERAL

Recognizing the need for knowledge regarding protection afforded by conventional structures against hazards of nuclear radiation, the Civil Effects Test Operations (CETO), Division of Biology and Medicine, U. S. Atomic Energy Commission, has conducted a series of measurements to evaluate the protection characteristics of conventional buildings against fallout. During the planning stages for a survey to be conducted at the Laboratory of Nuclear Medicine and Radiation Biology at the University of California at Los Angeles (UCLA) to determine the inherent fallout-radiation protection capability of the laboratory structure, the Los Angeles Office of Civil Defense requested that measurements be made at other structures in the Los Angeles area. This office further requested that the equipment used for determining such protection capabilities be demonstrated at the U. S. Civil Defense Council Conference, Oct. 16 to 20, 1961. Civil Effects Test Operations was happy to comply with these requests.

Three structures were chosen on the basis of their ability to provide maximum benefits for both the AEC and the Los Angeles Office of Civil Defense.

In conjunction with the measurements, the protection offered by the structures was also calculated from a recent survey guide.[1]

The program, especially that part concerning the Los Angeles Police Department building, received a considerable amount of publicity. All the publicity was favorable, thereby enhancing general public education and the over-all civil defense program.

1.2 BACKGROUND

Consideration of the protection against fallout radiation provided by existing structures indicates that certain areas within these structures provide a greater or lesser degree of protection than other areas. The problem is to locate the area of greatest protection, assign a protective value to the location, inform those who might have occasion to need it, and suggest means of improving the protection, if advisable, at an acceptable cost.

Theoretical calculations can provide estimates of the protection in existing structures. However, calculations become difficult and intricate when consideration is given to different shielding materials, internal rooms and equipment, ground contours, and complicated shielding geometry. These effects may alter to a large extent the prediction of the degree of protection in a given structure.

In addition, calculations must be simplified if fallout-shelter surveys are to be conducted quickly and inexpensively. Any simplification of complex theoretical calculations develops potential error when broad assumptions are made to save detailed intricate mathematical

analysis. Actual measurements, useful by themselves for protection planning, provide a definite cross-check on short-cut simplification calculation methods.

Willard F. Libby, at the time he was a Commissioner of the U. S. Atomic Energy Commission, suggested that a sound procedure for conducting actual measurements would be to use radioactive sources to simulate a fallout-radiation field around a structure and to measure the radiation levels within the building and outside on the ground. Specific information on a given structure then could be applied to similar structures in estimating their protective qualities. In addition, the experience and knowledge obtained through experimentation would be added to the fund of technical facts to provide a correlation between theory and practical applications.

Civil Effects Test Operations initiated a program utilizing such a procedure in 1958. The general objective was to gather data from a variety of structures, to use this information as the bases for developing and refining practical and simplified methods of predicting the protection provided by existing structures against fallout, and to make available practical information that could be used as design criteria for new structures.

The measurements made during the project reported here are a part of the continuing program. The results were the basis for selecting the best shielded areas inside the structure and for indicating any necessary changes or additions in construction to increase the protection.

1.3 OBJECTIVES

The objectives of this project were (1) to measure radiation levels at various locations inside four distinctly different types of structures, (2) to demonstrate the simplicity and safety by which such measurements could be made, and (3) to compare results based on measurements with simplified estimates of the fallout protection.

1.4 DESCRIPTION OF THE STRUCTURES

1.4.1 University of California at Los Angeles Structure

This structure is a large two-story building with a basement under the west section (Fig. 1.1). The summation of the floor thicknesses between basement and roof is 27 in. of concrete. The basement ceiling level is approximately 4 ft above ground level. Two small areaways in the rear of the building near the air filter system are at the basement floor level. Ground elevations relative to the building are shown in Fig. 1.2. Typical wall and floor sections are illustrated in Fig. 1.3. Floor plans are presented in Chaps. 3 and 4 in conjunction with the data. Figure 1.4 is a photograph of the storage area in the basement.

1.4.2 Home Fallout Shelter

A fallout shelter in a large ranch-style home in Los Angeles was selected as one of the structures to be tested (Fig. 1.5). The fallout shelter is located directly under one of the rooms of the house. The roof of the shelter is below ground level and is composed of 24 in. of concrete. An approximate floor plan is presented in Fig. 3.4.

1.4.3 Los Angeles Police Department Building

This building is a very large eight-story structure with rather complicated shielding geometry (Figs. 1.6 and 1.7). The communications section, the area of interest, is located in one corner near the outside (Fig. 1.8). The teletype room is not located under the eight-story structure but has a roof directly over it. Figure 1.9 shows a typical east-wall section of the teletype room, and Fig. 1.10 shows a typical south-wall section (next to the upstairs parking lot). Floor plans are presented in Fig. 3.5.

1.4.4 Typical Classroom Building at North Hollywood High School

This structure is a two-story building (Fig. 1.11) with dimensions of approximately 70 by 180 ft. It contains many windows and openings to the outside. Outer walls are 12-in.-thick concrete, and the inner walls are plasterboard. Figure 1.12 shows the location of the structure studied in relation to other school buildings. Figure 1.13 shows a typical wall section of the structure. Floor plans are presented in Fig. 3.6.

1.5 TECHNICAL DEMONSTRATION PROGRAM

One of the program objectives was to demonstrate the simplicity and safety with which radiation measurements could be made. It was considered to be important that civil defense officials be made aware of the existence of the equipment and of the general objectives of the program. Demonstrations of the equipment to public officials and reports in news media also aided the general public in a better understanding of radiation problems.

Several members of city organizations participated in the program and are mentioned in the Acknowledgments.

Before measurements were started, a combined press conference and demonstration was conducted at the Laboratory of Nuclear Medicine and Radiation Biology at UCLA. Among the principal speakers were Robert L. Corsbie, Willard F. Libby, Joseph F. Ross, and Joseph M. Quinn. The press conference and demonstration received enthusiastic publicity, being given coverage by television newscasts and newspaper articles.

After the measurements the equipment was set up at the Ambassador Hotel and was demonstrated to top civil defense officials during the U. S. Civil Defense Council Conference. The demonstration setup is shown in Figs. 1.14 and 1.15.

REFERENCE

1. Fallout Shelter Surveys: Guide for Architects and Engineers, Office of Civil and Defense Mobilization Report NP-10-2, May 1960.

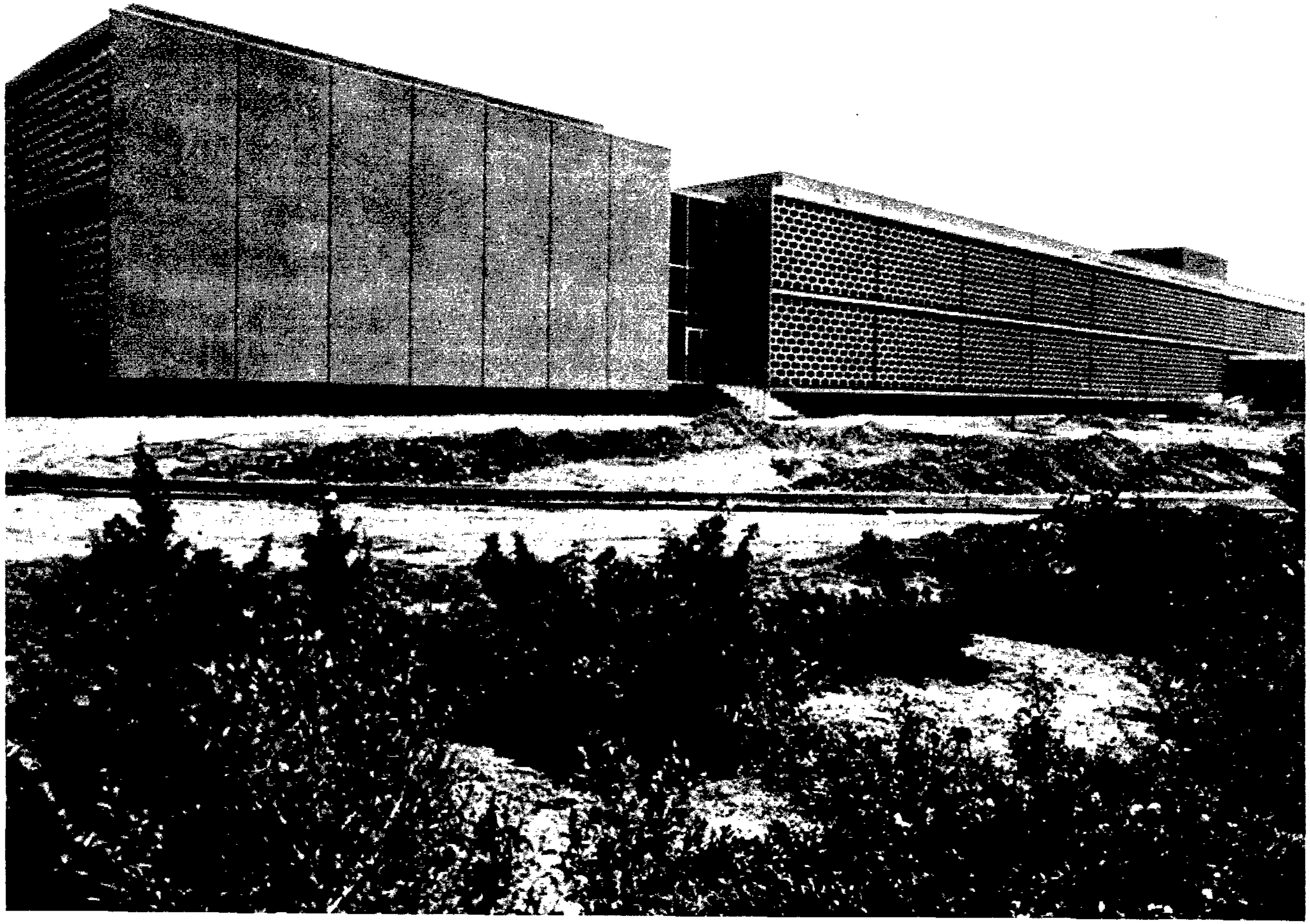


Fig. 1.1—General view of the Laboratory of Nuclear Medicine and Radiation Biology at UCLA.

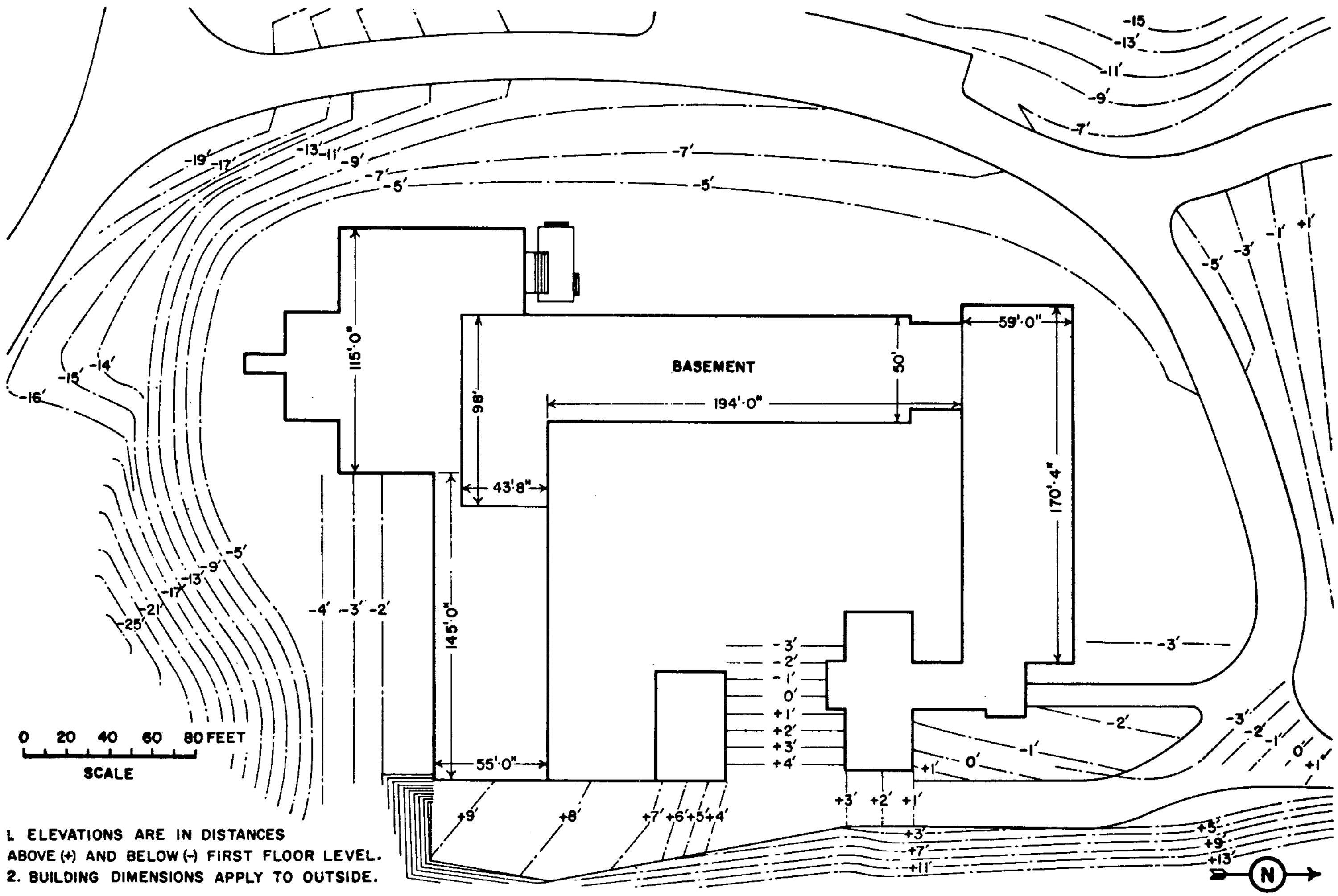


Fig. 1.2—Approximate ground elevations relative to UCLA structure.

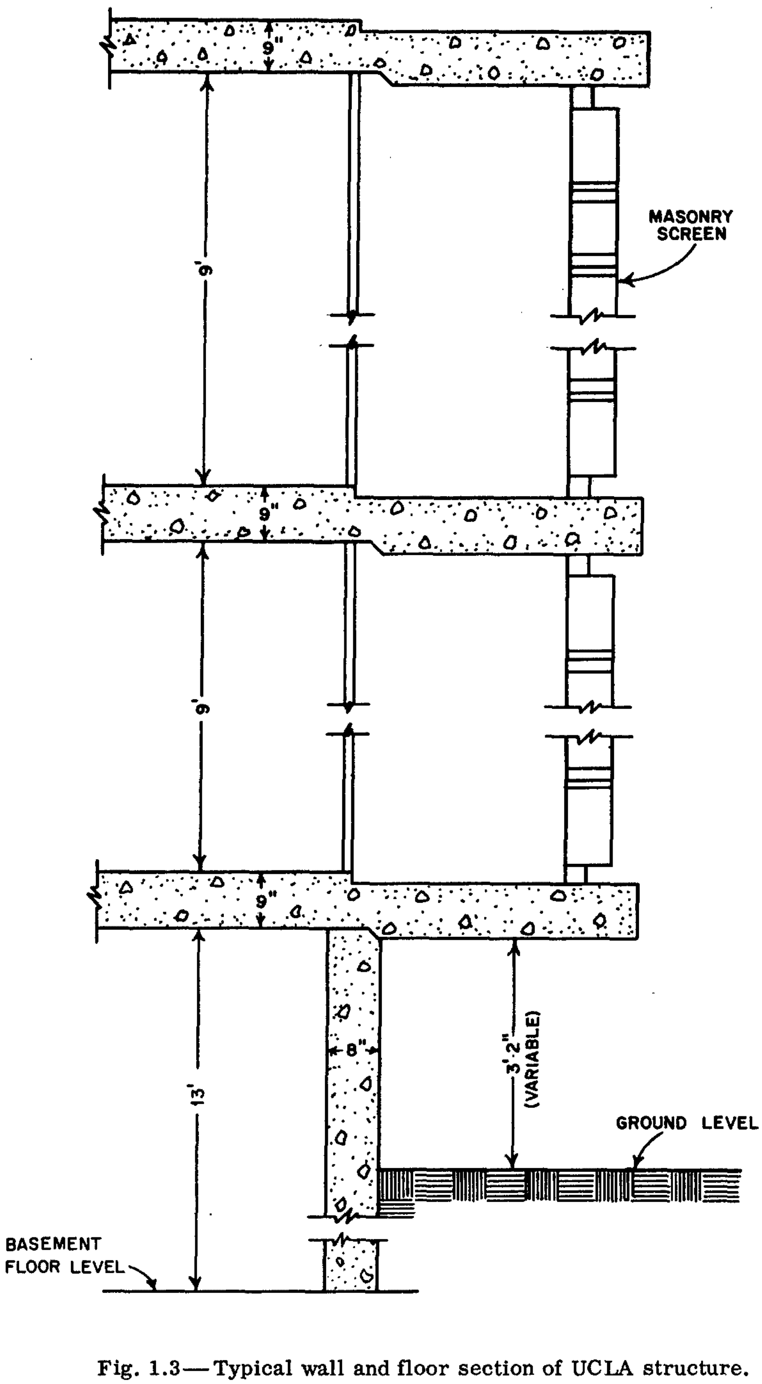


Fig. 1.3—Typical wall and floor section of UCLA structure.

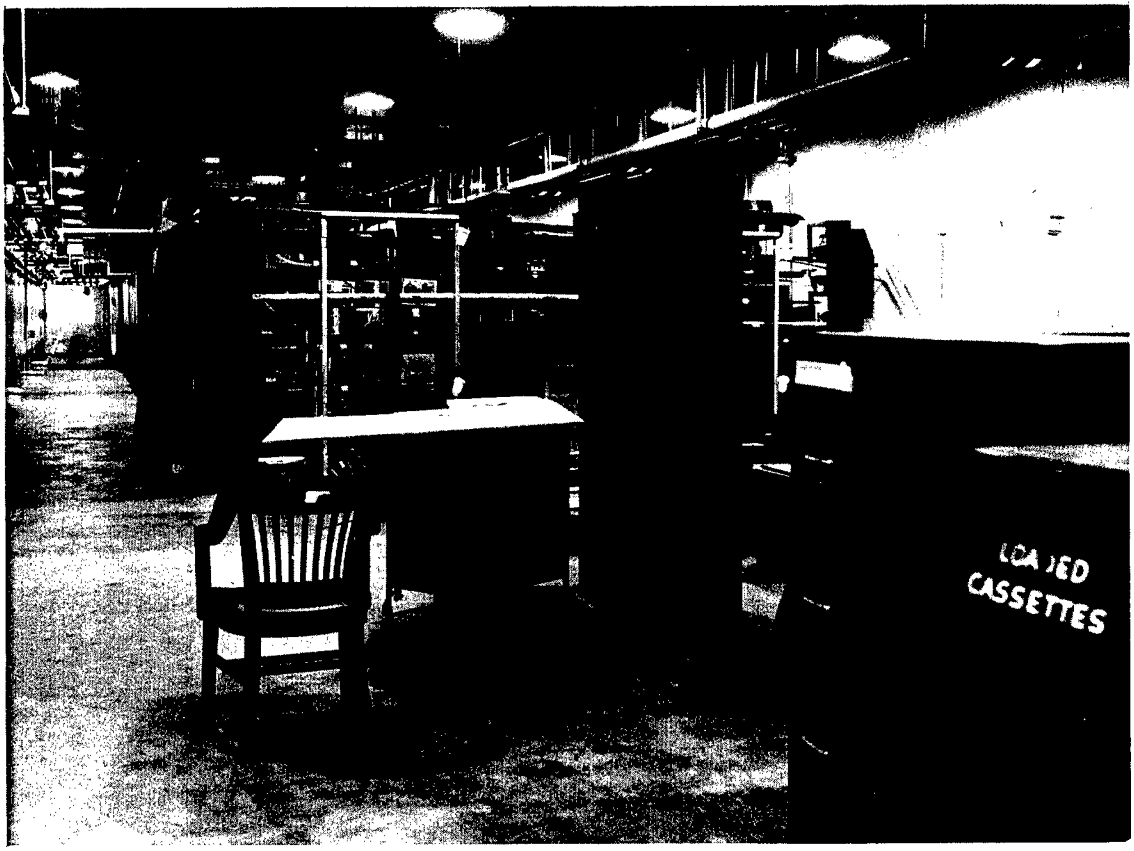


Fig. 1.4—View of storage area in basement of UCLA structure.

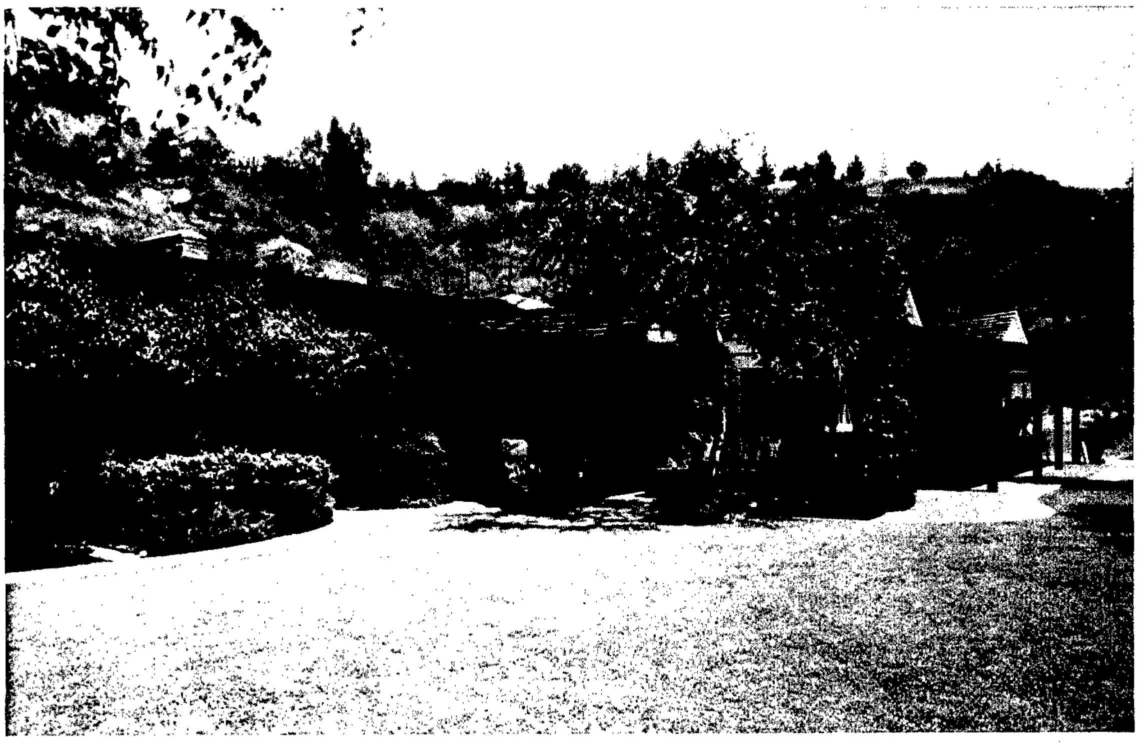


Fig. 1.5—Los Angeles residence with fallout shelter under house.

Fig. 1.6—General view of the Los Angeles Police Department building showing upstairs parking lot.

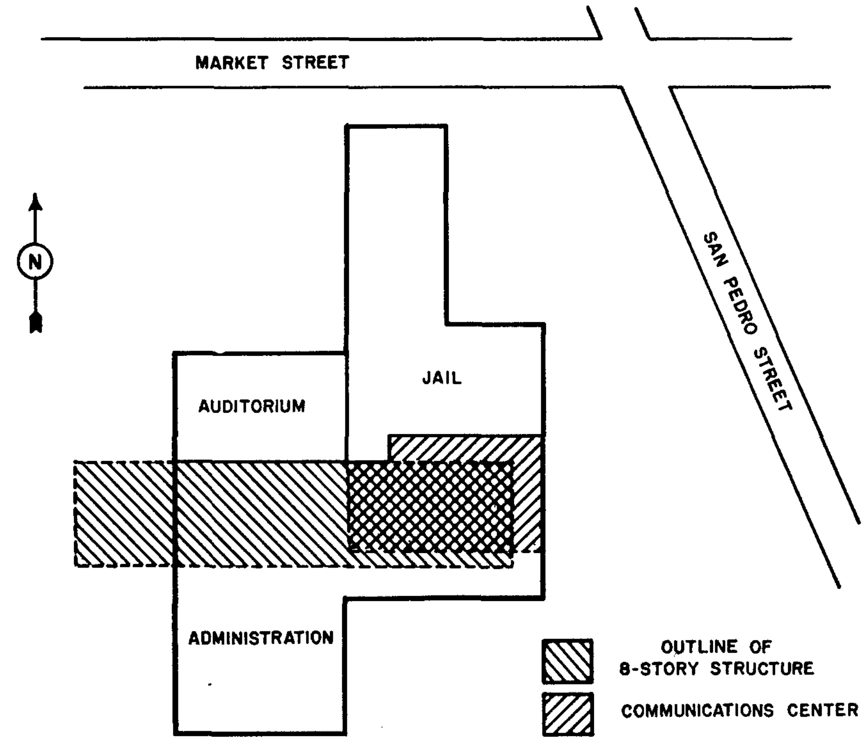


Fig. 1.7—General floor plan of Los Angeles Police Department building.

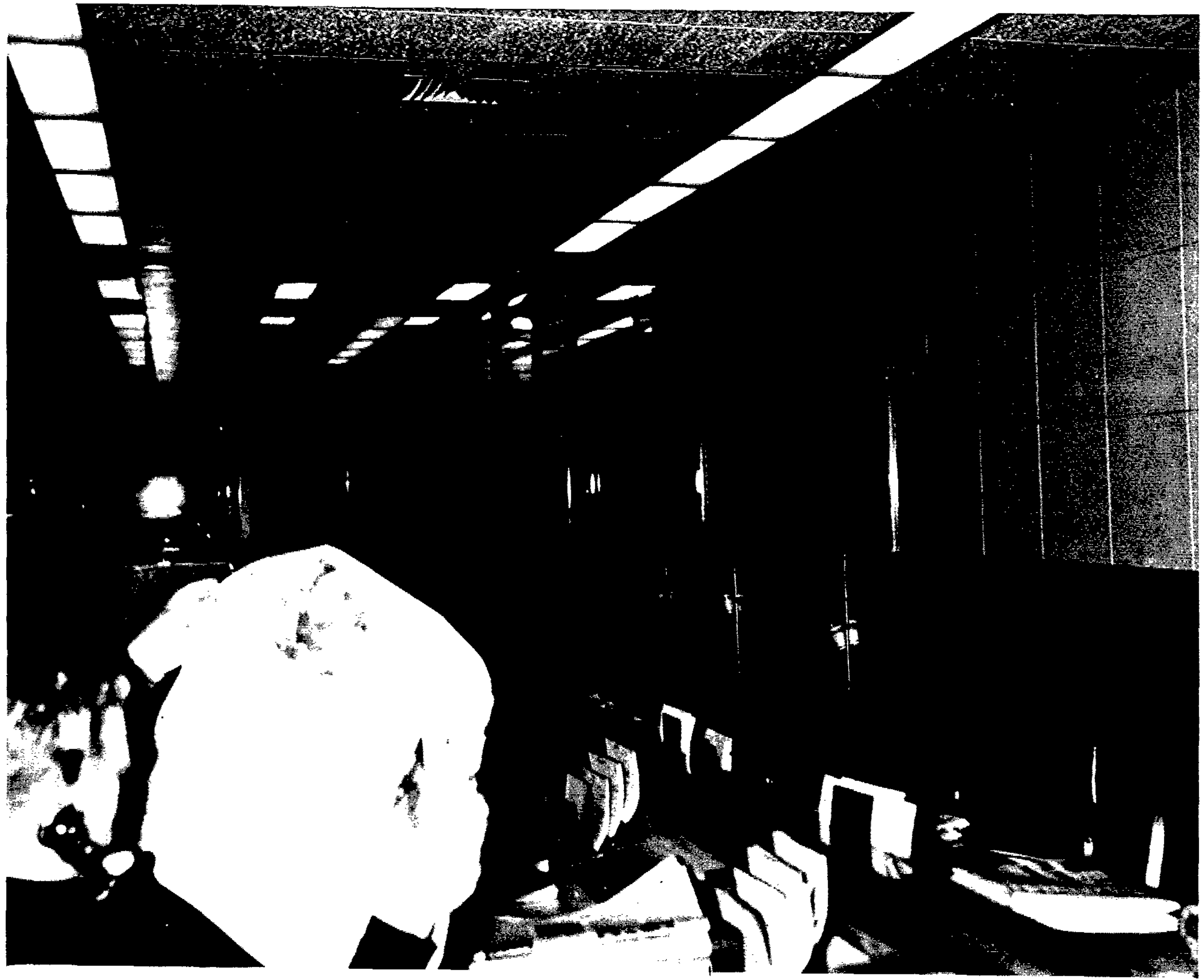


Fig. 1.8—Communications section of Los Angeles Police Department building.

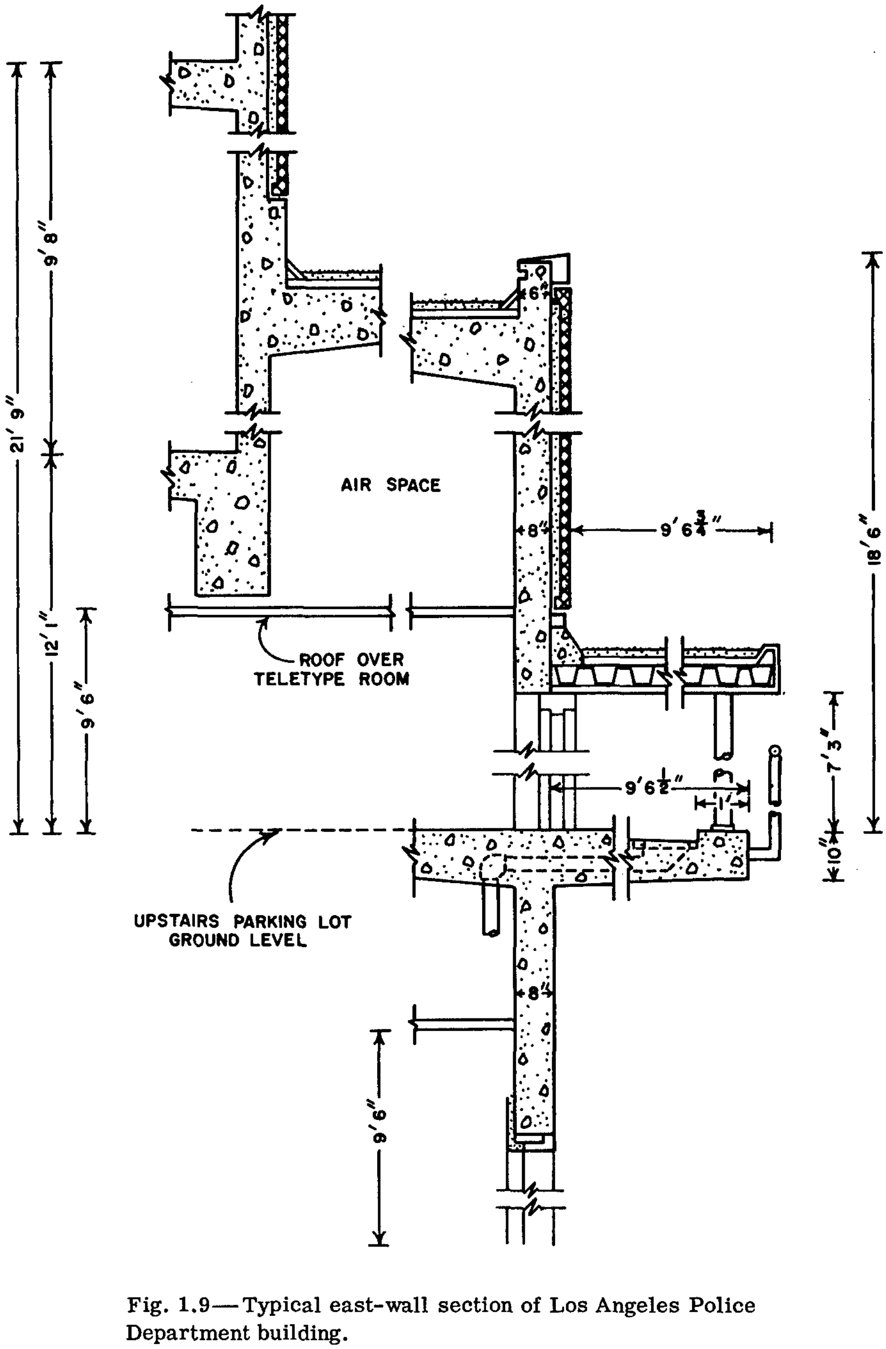


Fig. 1.9—Typical east-wall section of Los Angeles Police Department building.

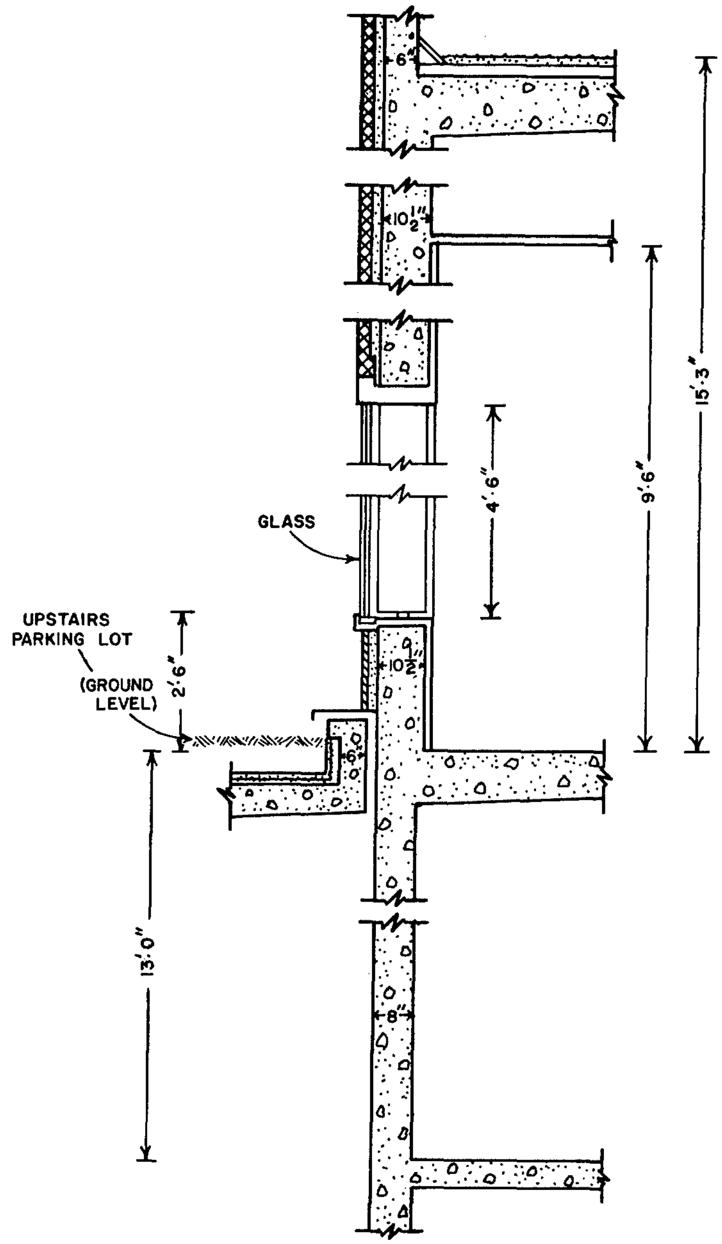


Fig. 1.10—Typical south-wall section of Los Angeles Police Department building.

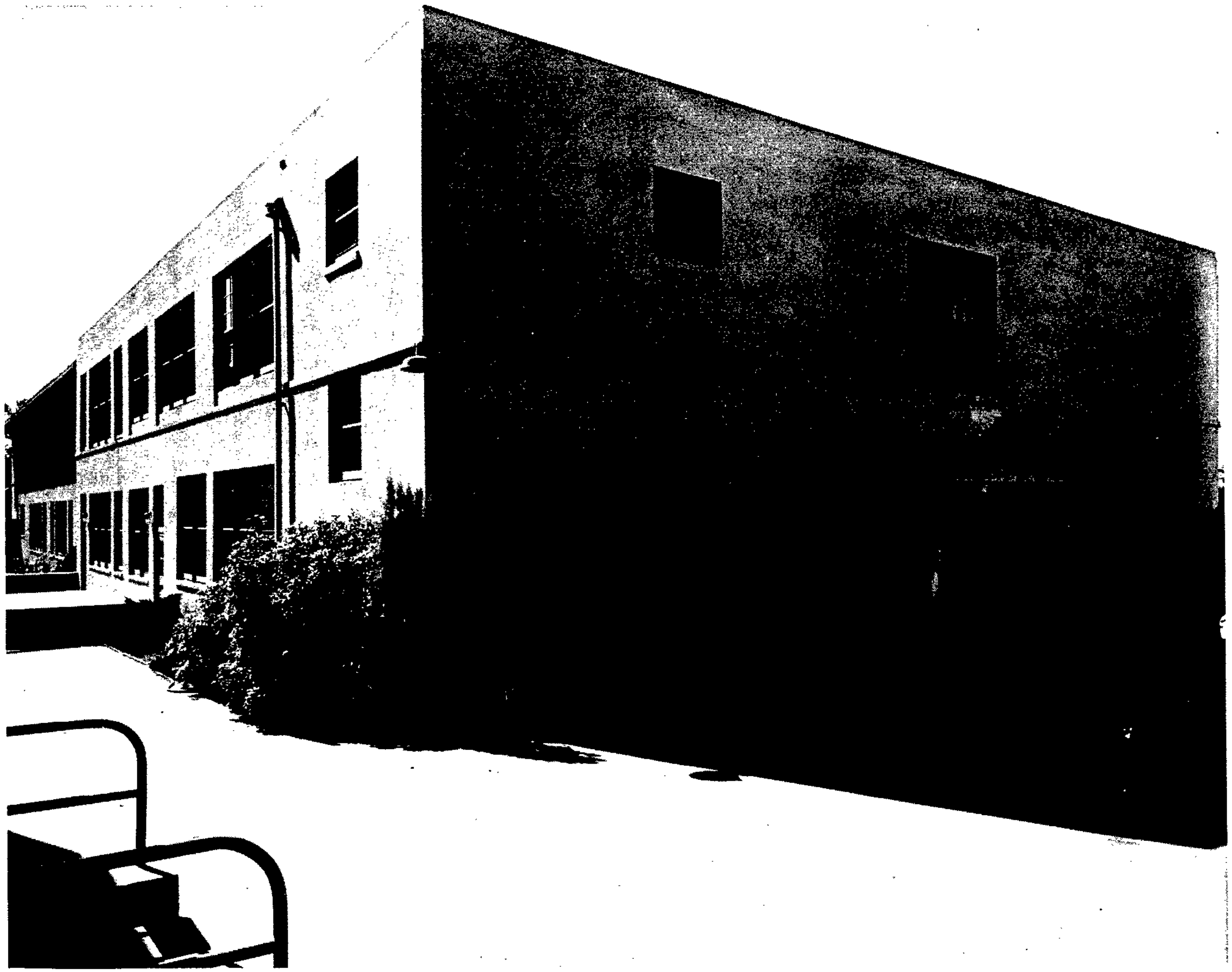


Fig. 1.11—General view of classroom structure at North Hollywood High School.

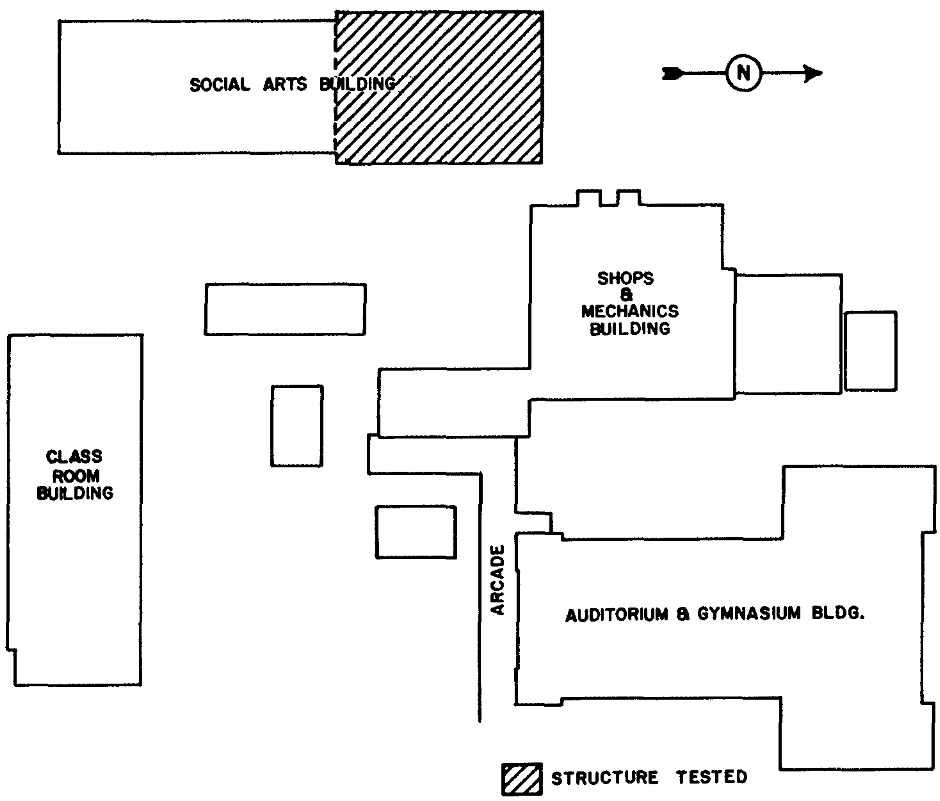


Fig. 1.12— Partial plan view of North Hollywood High School.

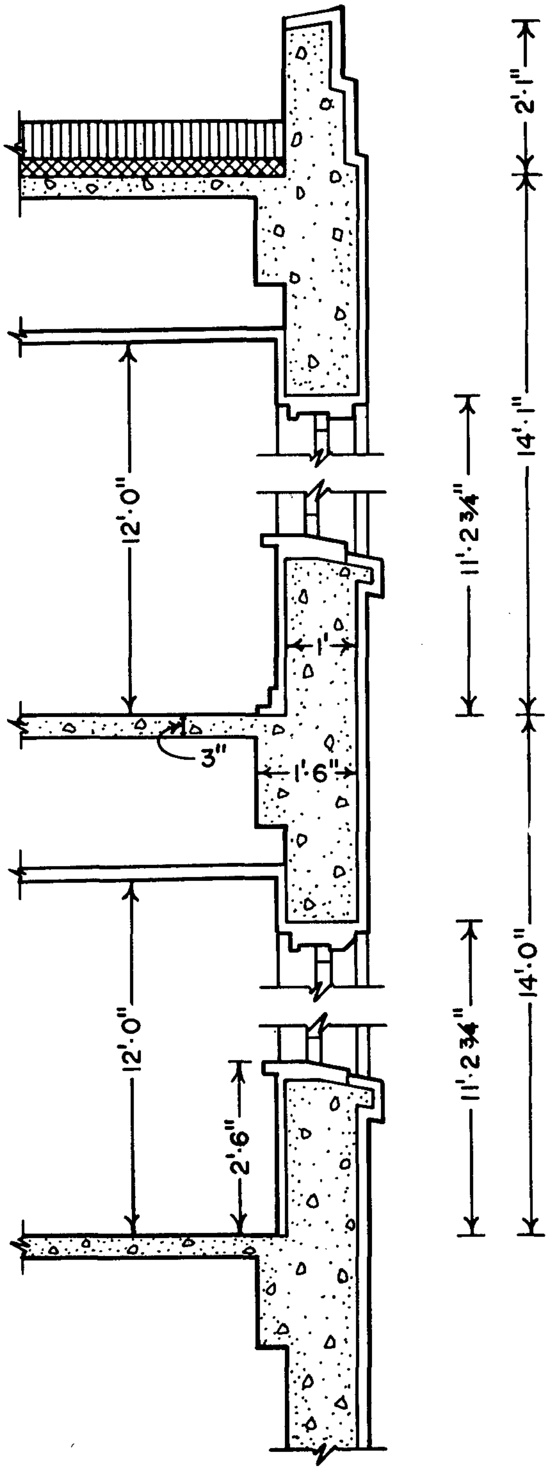


Fig. 1.13—Typical wall section of North Hollywood High School classroom structure.

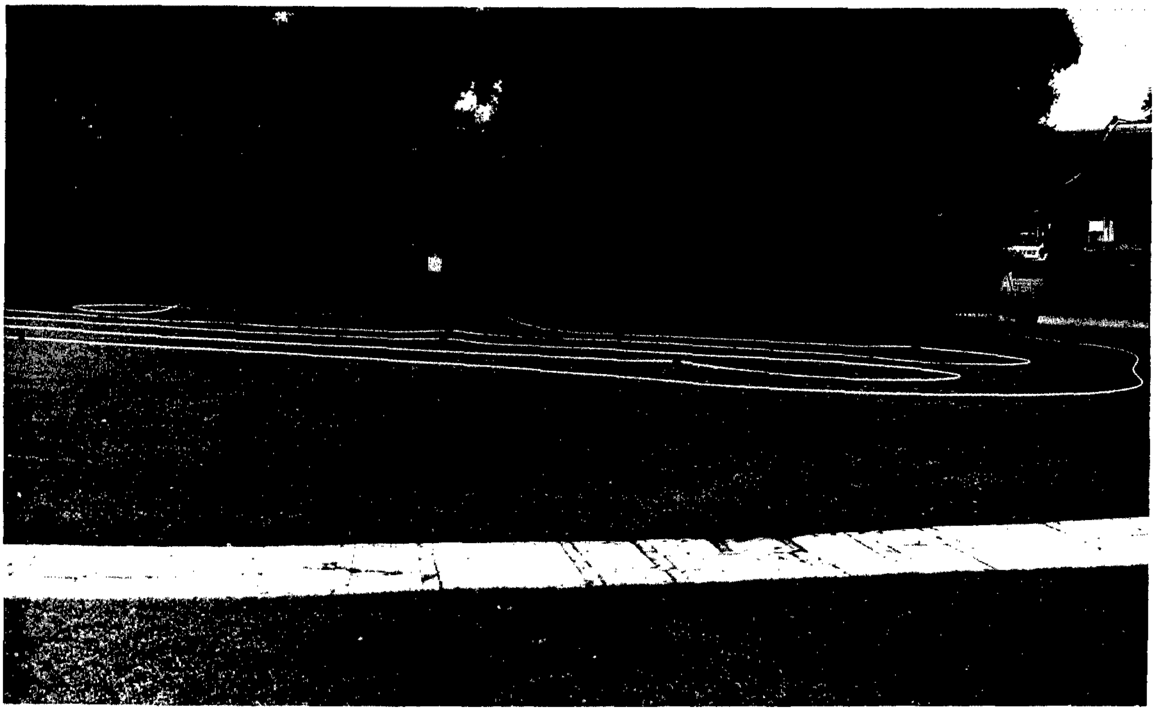


Fig. 1.14—Demonstration setup at Ambassador Hotel.

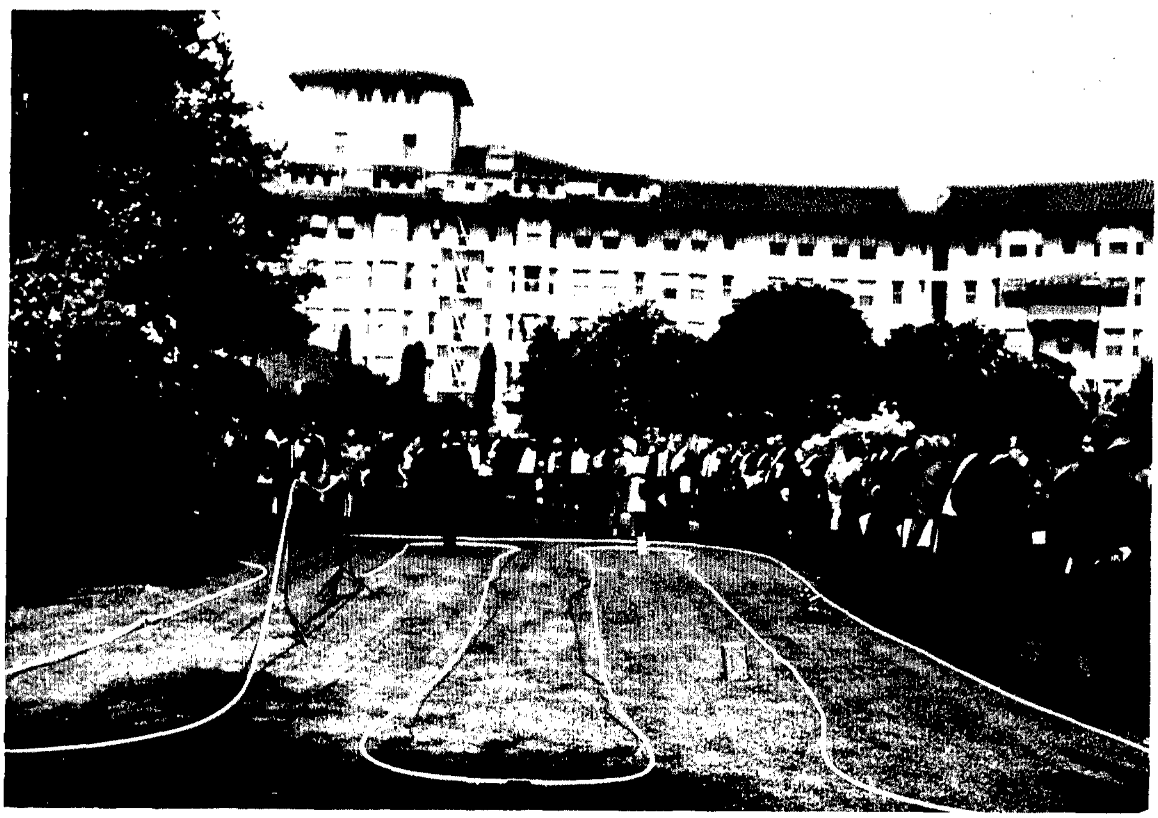


Fig. 1.15—Demonstration of equipment at Ambassador Hotel.

Chapter 2

DESCRIPTION OF THE EXPERIMENTAL METHOD

2.1 GENERAL DESCRIPTION

A fallout-radiation situation was simulated on appropriate areas on the ground outside and/or on the roof of the structure being tested. Detectors were placed within the buildings at preselected positions to record the radiation levels. Fallout radiation was simulated by the use of the Mobile Radiological Measuring Unit (MRMU).

This unit employed a single moving radioactive Co^{60} source hydraulically pumped through polyethylene tubing. The tubing was laid over the area of interest in such a manner that the amount of tubing per unit area was constant. Since the source traveled at a uniform speed, an area of uniformly distributed radioactivity was simulated. Thus fallout radiation was simulated since fallout, under idealized conditions, is uniformly deposited over large areas. A Co^{60} source was used because the energy of the gamma radiation emitted (1.17 and 1.33 Mev) closely approximated the effective energy of gamma radiation from fallout. As the source was pumped through the tubing, accumulated radiation doses were measured inside the structure at desired positions with highly sensitive ionization chambers (dosimeters). These dosimeters, being integrating units, detected radiation intensity from this moving point-source simulation to provide the same results that would be experienced from a similar field contaminated by fallout radiation.

A point source was used to simulate the accumulation of fallout in air filters and vents where appropriate.

2.2 MOBILE RADIOLOGICAL MEASURING UNIT

The equipment that made up the MRMU system, which was truck-mounted for mobility, consisted of a hydraulic pumping unit, one mile of tubing, source-position indicators, a remote-control console, several Co^{60} sources, source shields, Co^{60} source containers, interconnecting cables, ionization chambers and associated charger readers, and a 256-channel analyzer with associated equipment. From the control center the hydraulic pumping system was activated, and the Co^{60} source was pumped from the shield through the tubing, arranged over the area of interest, and back into the shield. Figure 2.1 is an operational diagram of the system. As the source traveled through the tubing, dosimeters in the building accumulated the radiation dosage, and source-position indicators attached to the tubing told the control center the exact location of the source.

The MRMU system was contained in three vehicles. The hydraulic system and source shields were mounted on one truck. Tubing reels and power- and signal-cable reels were mounted on a caisson trailer. A laboratory truck (Fig. 2.2) contained the control console, the data readout equipment, tools, supplies, and the general equipment for the system. The entire system was practically self-sufficient.

The strength of the Co^{60} source used depended upon the structure being tested. Source strengths from 100 mc to 300 curies have been used, as required, according to the type of structures being measured and the precautions necessary to minimize personnel exposure.

All Co^{60} sources were encapsulated in magnetic stainless-steel containers (slugs) accurately machined to pass through the inside of the plastic tubing. The large source (266 curies) was doubly encapsulated (a capsule within a capsule). It was about 2 in. long (Fig. 2.3). The capsules were Heliarc-welded and passed all AEC leak tests.

Shielded storage was provided for the sources when they were not being pumped through the tubing. Figure 2.4 is a photograph of the large Co^{68} source shield. Within this shield were two S-shaped stainless-steel tubes in which the slug traveled. Stops were provided in the center of each tube to halt the motion of the slug when it returned to the shield. A method was provided to secure and lock the source in place when it was not being used. Two source shields, an air compressor (used to empty the water from the tubing), and the hydraulic system were mounted on the same truck (Fig. 2.5).

The hydraulic pumping system consisted of a 120-gal reservoir, a 1-hp 220-volt electric motor, a piston type positive-displacement pump, filters, several hand-operated and electrically operated solenoid valves, and connecting lines. The outside diameter of the source capsule was slightly less than the inside diameter of the tubing, thus a flow system rather than a pressure-differential system was utilized. In normal operation the internal pressure was about 100 psi when 3000 ft of tubing was used. At this pressure the source traveled at approximately 120 ft/min.

The slug was conveyed by water (anti-freeze would be added in cold weather) through 0.5-in. Marlex (high-density polyethylene) tubing that was rated at 200-psi hoop stress at 130°F for a one-year period. Burst pressure was rated in excess of 1000 psi. The tubing bend radius was usually limited to a minimum of 2 ft for assurance of safe passage of the Co^{60} source. Up to 5000 feet of tubing was used for a test run.

Hydraulic operation of the system was reversible with maximum speed obtainable in either direction. The control system had the capability of stopping the source at any given position. The system was operated and controlled remotely from a console (Fig. 2.6) located in the laboratory truck a safe distance from the pumping system.

On the panel of the console was a series of lights; these lights were connected individually to magnetic position indicators (Fig. 2.7) on the tubing, thus providing an indication of the location of the source capsule.

An emergency hand pump (Fig. 2.8) could have retrieved the slug from either direction if the main pumping unit had failed during actual operation.

Several hundred ionization chambers were available for the experiment. The majority of these chambers were Victoreen model 362 0- to 200-mr chambers and Victoreen model 239 0- to 10-mr chambers. Victoreen model 287 minometers were used for charging and reading the ionization chambers (Fig. 2.9).

Maximum safety precautions were taken. The MRMU system itself incorporated many safety features. Other safety precautions included effective preventative maintenance and pre-exposure checkout. Health physics monitoring equipment consisted of radiation meters, alarms, film badges, and pocket ionization chambers (see Fig. 2.10).

A stationary Co^{60} point source was also used. This system (Fig. 2.11) consisted of a source shield mounted on rubber wheels, a hand-powered control drive, and indicating lights. The Co^{60} was encapsulated in a container, which, in turn, was connected to a 50-ft steel control cable that traveled inside a flexible guide tube. This control cable passed over a crank-driven wheel in the control unit, which advanced or retracted the source, making it possible for the operator to stand 25 ft away from the shield and reel the source out to the desired location.

2.3 SOURCES

All radioactive sources used during this project were Co^{60}. These sources included one 266-curie source, one 16.5-curie source, one 13.5-curie source, and one 2.5-mc source. Other sources were available but were not used during this project.

Calibration of the 266-curie source was performed at the Nevada Test Site prior to the experiment. The polyethylene tubing was placed on two 15-ft poles, and the source was pumped into position and stopped directly between the two poles at a height of 12 ft. Victoreen r-meters, previously calibrated against National Bureau of Standards calibrated chambers, were used to measure the dose rate at 10 and 20 ft from the source at a height of 12 ft. The source was found to have a strength of 283 curies at the time of calibration (Apr. 10, 1961), assuming 14.53 r/hr/curie at 1 ft. It had decayed to 266 curies at the time of the experiment (Sept. 20 to Oct. 14, 1961).

The 16.5-curie source was calibrated in a similar manner and was found to have a strength of 17.0 curies at the time of calibration (Aug. 4, 1961).

The 13.5-curie source was a part of the point-source system. It was calibrated in the Santa Barbara, Calif., laboratories of EG&G.

The small 2.5-mc source was used for demonstration purposes.

2.4 INSTRUMENTATION

Instruments used in this project included several dose-integrating ionization chambers with associated charger readers and a Precision model III standard "scintillator."

Approximately 250 Victoreen model 362 chambers (200-mr full-scale pocket chambers) and 140 Victoreen model 239 chambers (10-mr full-scale stray-radiation chambers) were used. Victoreen model 287 minometers were used for charging and reading these chambers.

The chambers were calibrated with a Co^{60} standard. Chambers were picked at random and exposed several times to obtain an average dose and standard deviation at several points over the entire range of the chambers. Sample calibration curves and energy-response curves can be found in the report of a study conducted at Brookhaven National Laboratory.[1]

The Precision scintillator (Fig. 2.12) was used for measurements where the radiation levels were extremely low. The instrument was calibrated during the project against the model 239 chambers and indicated an agreement within 10 per cent using the scale of interest.

2.5 EXPERIMENTAL TECHNIQUE

2.5.1 General

The experimental technique consisted in measuring the radiation levels at points within the building from a simulated contaminated area of known source strength outside. The contaminated field was simulated by moving a point source at constant speed over the area of interest in such a manner that the source spent the same time interval per unit area throughout. The use of dose-integrating detectors within the building made the total radiation dosage appear to be arising from an area source. This technique has the advantage of averaging local features of the terrain and the building under test. These are features that would be of significance in a true fallout-radiation field.

General procedures that were followed during a study at a structure were essentially the same regardless of the complexity of the structure. These procedures consisted of the following steps:

1. Equipment arrived at the site and was unpacked, set up, and checked out.
2. Detector positions were established inside the structure at selected points. Detectors were placed in paper cups attached to strings hung either from the ceiling or from aluminum stands.
3. Polyethylene tubing from the mobile unit was distributed over the desired area according to a predetermined plan.
4. A dummy source (containing no radioactivity) was pumped through the tubing to assure that the tubing had not been damaged during placement. At that time the detectors were charged and placed in their preplanned locations.

5. When radiological safety clearance was given, the system was energized and an exposure was made. More than one exposure was made at most structures. Exposures varied from a few minutes to a few hours, depending upon the location and situation.

6. At the end of an exposure, the source was secured in its container, the dosimeters were read, and their readings were recorded.

7. At the end of a test, standard wrap-up procedures governing handling of the MRMU and related equipment were thoroughly carried out prior to moving to a new test site.

In general, the exposures were made at night or on weekends to minimize the inconvenience to all concerned. A radiological safety plan was formulated and followed for each test (see Appendix A) to assure maximum safety to personnel.

2.5.2 University of California at Los Angeles Structure

The Laboratory of Nuclear Medicine and Radiation Biology on the campus of UCLA was chosen for study because its construction geometry was considerably different from a similar complex structure previously studied at Brookhaven National Laboratory.[1] The UCLA laboratory has two stories with a basement and intervening thick concrete floors, an arrangement which would result in very little or no radiation contribution from the roof in the event of a fallout situation. At the structure at Brookhaven National Laboratory, the roof radiation contribution was very large.

The basement was selected as the area of detailed study. Measurements were also made at a few points on the first and second floors. If fallout contamination were present over and around the laboratory structure, radiation arriving in the basement would be coming from essentially four different sources: (1) contamination on the ground outside, (2) contamination on the roof, (3) contamination in the areaways at the rear of the building, and (4) contamination in the filter system (if the air-circulation system were operating while fallout was coming down).

So that the contribution from contamination on the ground outside could be evaluated, the tubing was evenly distributed over a large area in front of the building. This area was 72 ft wide and extended from the front entrance to the north end of the building. The 266-curie Co^{60} source was pumped through the tubing for a 1-hr exposure. Measurements also were made with the tubing spread over an area 60 ft wide at the rear of the building.

Figure 2.13 shows an outline of the structure with the basement and the measurement areas indicated. The X's indicate approximate positions of point sources.

Figures 2.14 and 2.15 show the tubing layout in the front and in the rear of the structure. Sandbags and barrels of sand were used in the rear to attenuate a portion of the radiation and thereby reduce exposure to residential areas (see Appendix A).

The two areaways to the rear of the basement were at the basement floor level. Tubing was placed in the large areaway and the 16.5-curie source was pumped through it for 30 min (Fig. 2.16). A point source of 13.5 curies was placed at three locations in the small areaway, and the dose rate was measured at appropriate positions within the structure.

Although there were approximately 27 in. of concrete between the roof and the basement, it was deemed advisable to demonstrate that the fallout-radiation contribution through the roof was negligible. This was done by stopping the 266-curie source at three positions on the roof and measuring the radiation level at appropriate locations within the building. Sandbags were used to reduce radiation exposure to the surrounding residential areas (Fig. 2.17).

The point source of 13.5 curies was placed near the filters in the fan room to ascertain the effect of a buildup of contamination in the filter system. Its exact location was 4 ft above the floor, 7 ft from the west wall, and 9 ft from the north wall in the fan room next to the large areaway (see Fig. 4.4).

A portion of the basement was used for storage (Fig. 3.1). Figures 2.18 and 2.19 show detector locations in the basement hallway and storage area.

2.5.3 Home Fallout Shelter

A Los Angeles residence was studied to determine the radiation protection provided by a below-ground-level fallout shelter. Since the fallout shelter is completely below ground level,

under one room of the house, the most of the radiation reaching the inside of the shelter would be expected to originate on the roof of the house. Therefore fallout radiation was simulated on a large part of the roof and the inner patio, and radiation measurements were made inside the shelter.

The 16.5-curie source was used rather than the larger source because of the nearness of neighbors. The source was stopped on the roof and in the patio, and the dose rate was measured inside the shelter to estimate the contribution of the radiation coming through the roof and of that scattering through the entrance way. Figure 2.20 shows the tubing layout on the roof of the house.

2.5.4 Los Angeles Police Department Building

The communications center of the Los Angeles Police Department building was studied. Since this was a large complicated structure, radiation measurements were limited to selected areas, the results of which were used as guide lines in estimating the protection factors.

Note that a portion of the communications section (teletype room) shown in Fig. 1.8 is not under the eight-story structure but has a roof directly above it. For one measurement the tubing was placed over a portion of this roof, and measurements were made in the teletype room and at selected locations throughout the communications section. Photographs of the locations appear in Figs. 2.21 and 2.22. Entrance into the teletype room during the test was limited and controlled (see Appendix A).

Figure 3.5 shows detector locations and a floor plan of the communications section. Figure 2.23 shows a plan view of the building and locations of areas where the tubing was placed.

Before measurements were made, an investigation showed that the inside walls were essentially either glass or plasterboard. In addition, the outside wall next to the parking lot was all glass except for the bottom $1\frac{1}{2}$ ft, which was approximately 12-in.-thick concrete. Tubing was placed on the upstairs parking lot from the building out to a distance of 36 ft (Fig. 2.24). The 16.5-curie source was used rather than the larger source because of the proximity of working personnel.

Dose rates, which were extremely low, were measured by the low-range Precision scintillator.

2.5.5 Typical Classroom Structure at North Hollywood High School

A typical classroom structure at North Hollywood High School was chosen for study. Measurements were made during the weekend when the school was vacated.

Tubing was placed on the roof of the structure (Fig. 2.25), and the 266-curie source was used to determine the roof contribution. Measurements were made at selected points in the hallway and rooms on the first floor only (Fig. 2.26). Tubing was placed on two separate areas outside (Figs. 2.27 and 2.28) to aid in evaluating the ground contribution. Operational limitations were such that extensive measurements were not possible, and the nearby residential areas prohibited the use of the large source on the ground. As a result measurements made from the two small areas were used as guide lines in estimating the ground contribution. The 16.5-curie source was used at both areas.

REFERENCE

1. H. Borella et al., *Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center*, Report CEX-60.1, October 1961.

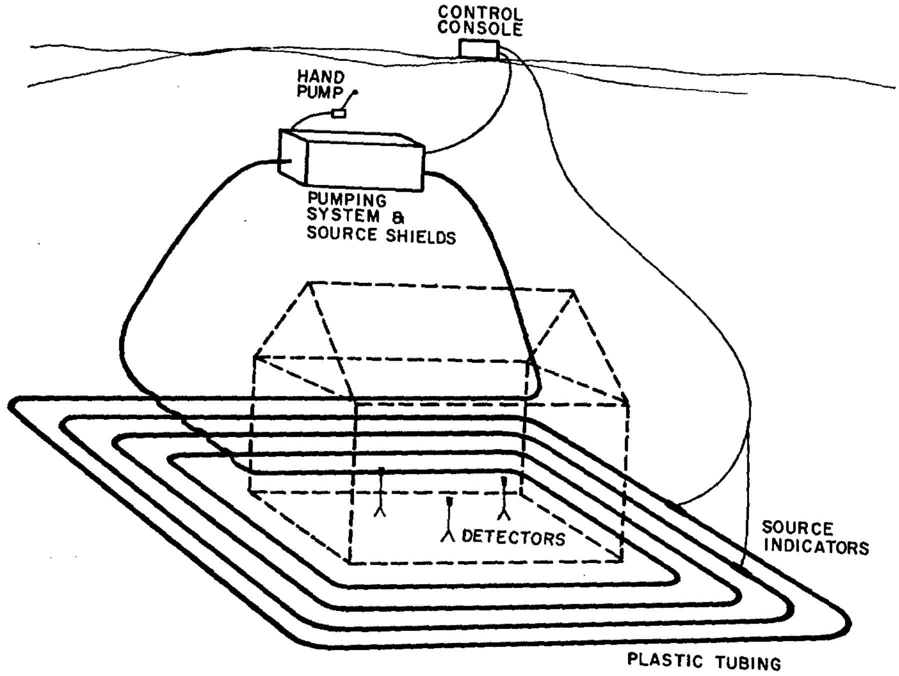


Fig. 2.1—Operational diagram of the MRMU.

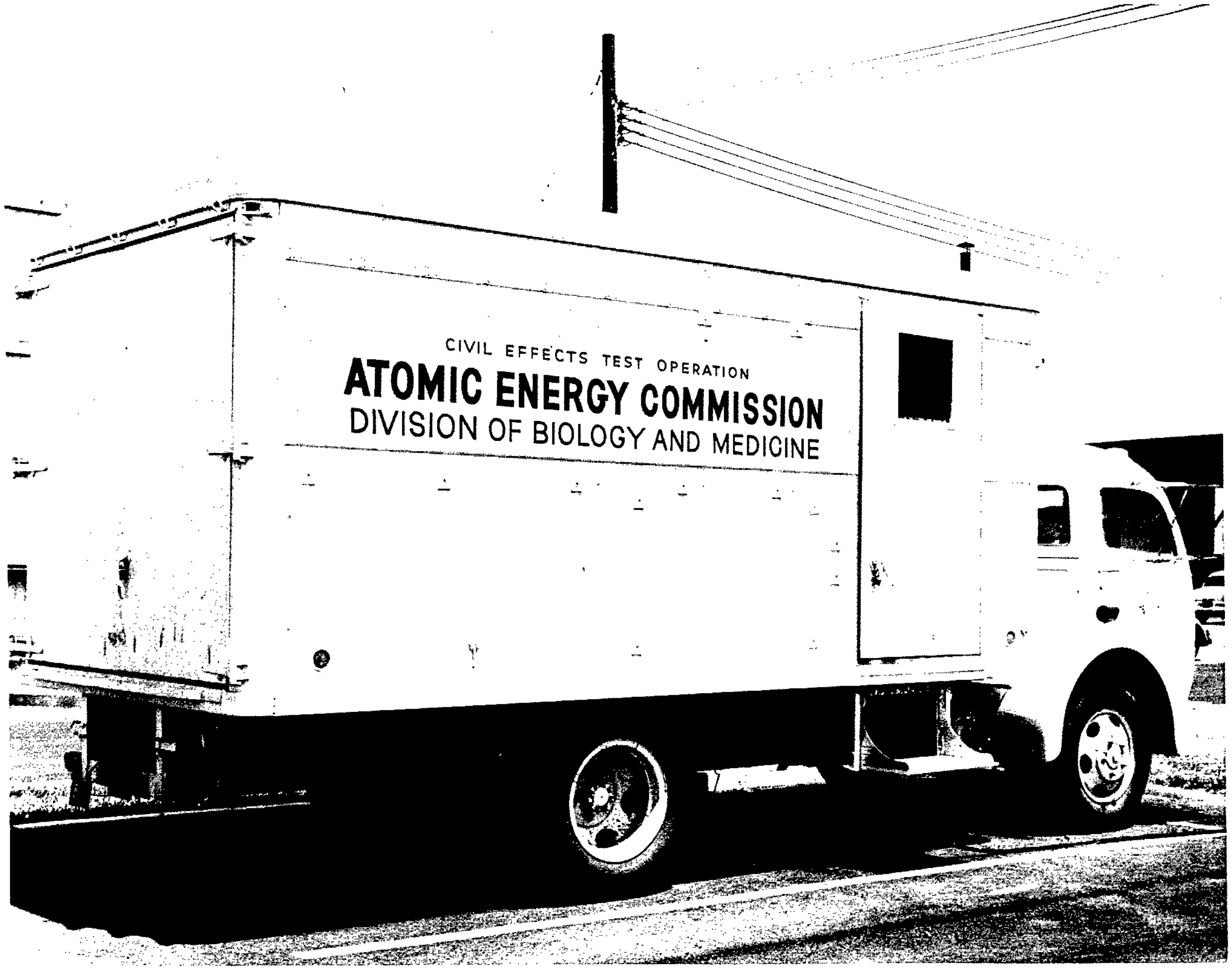
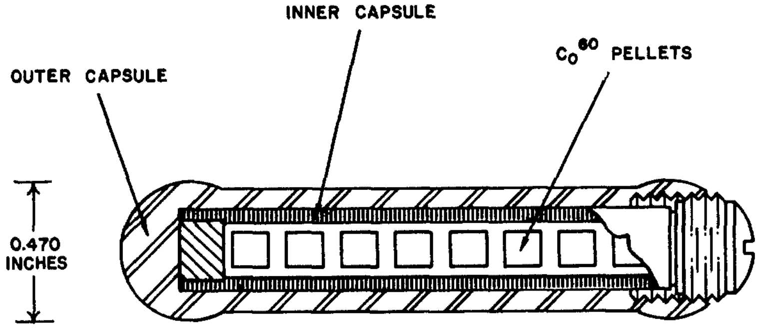


Fig. 2.2—Laboratory vehicle.



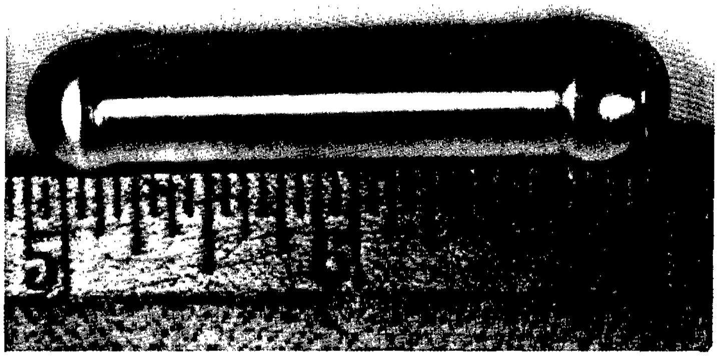


Fig. 2.3—The Co^{60} source capsule.

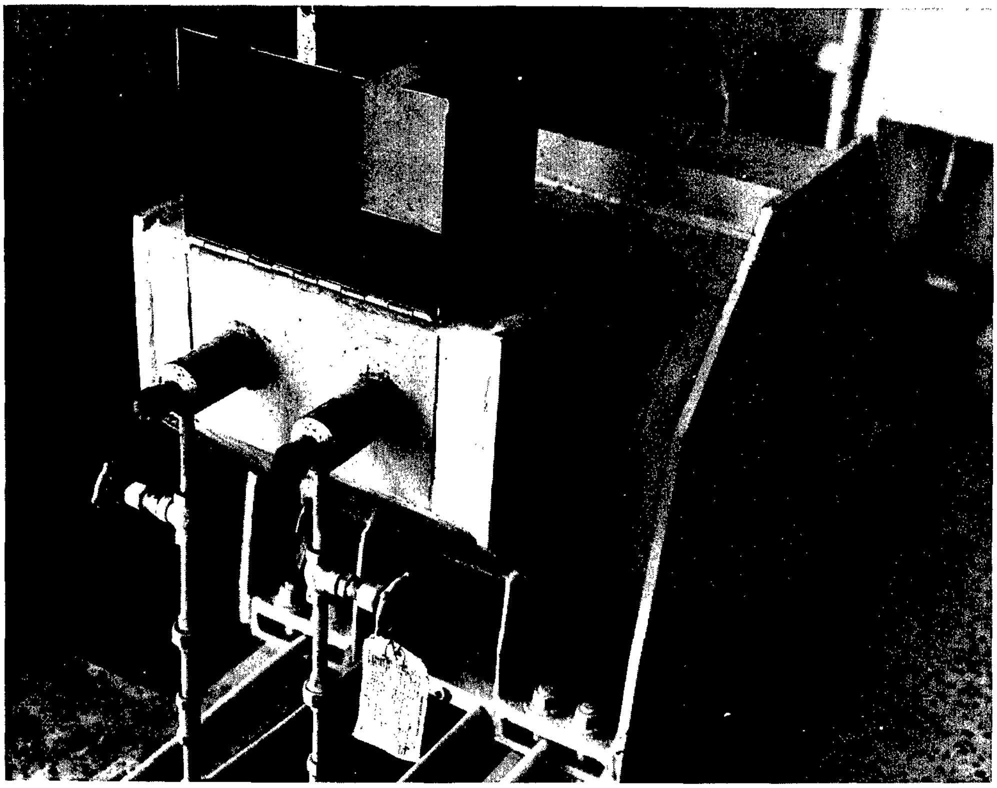


Fig. 2.4—Large Co^{60} source shield.

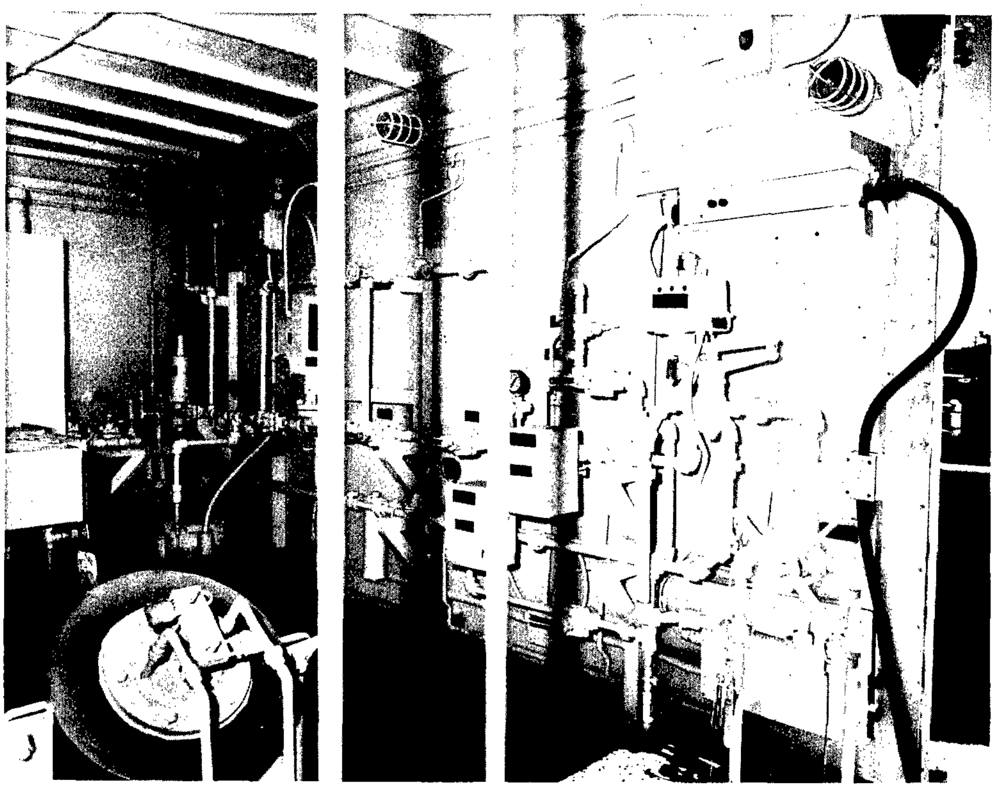


Fig. 2.5—Source truck showing shields and pumping system.

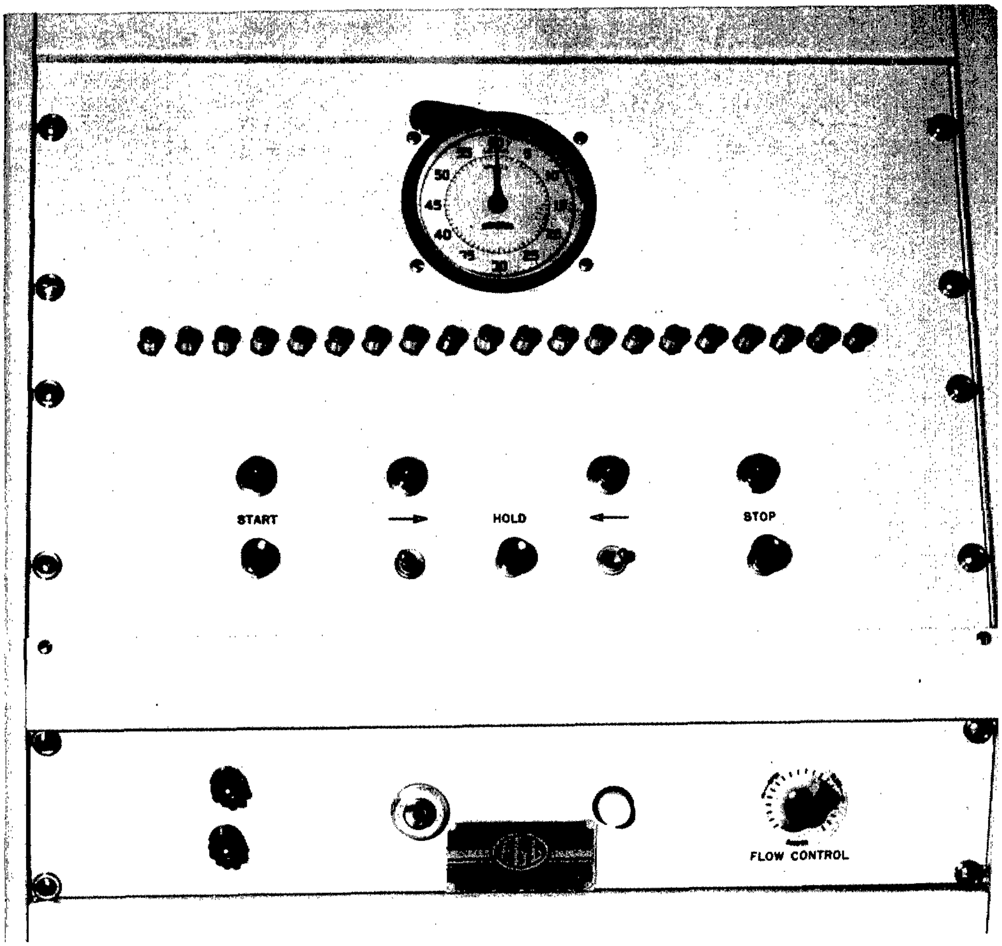


Fig. 2.6—Remote-control console.

Fig. 2.7—Source-position indicator.

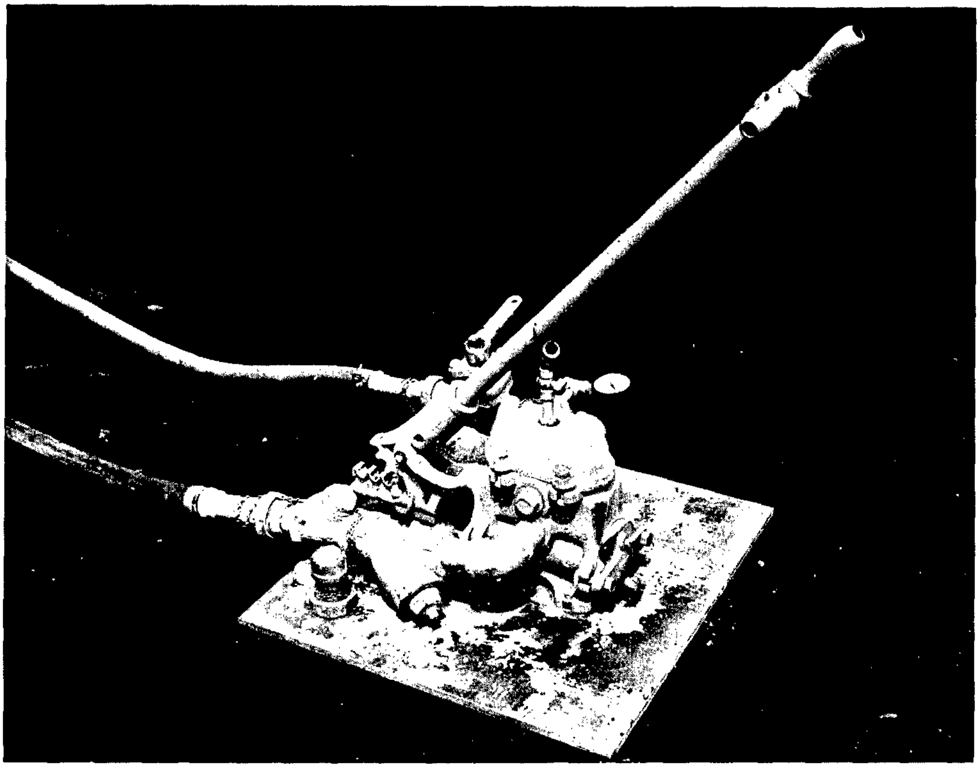


Fig. 2.8—Emergency hand pump.

Fig. 2.9—Ionization chambers and charger reader.

Fig. 2.10—Health physics instruments.

Fig. 2.11—Point-source system. (Photo taken at Nevada Test Site.)

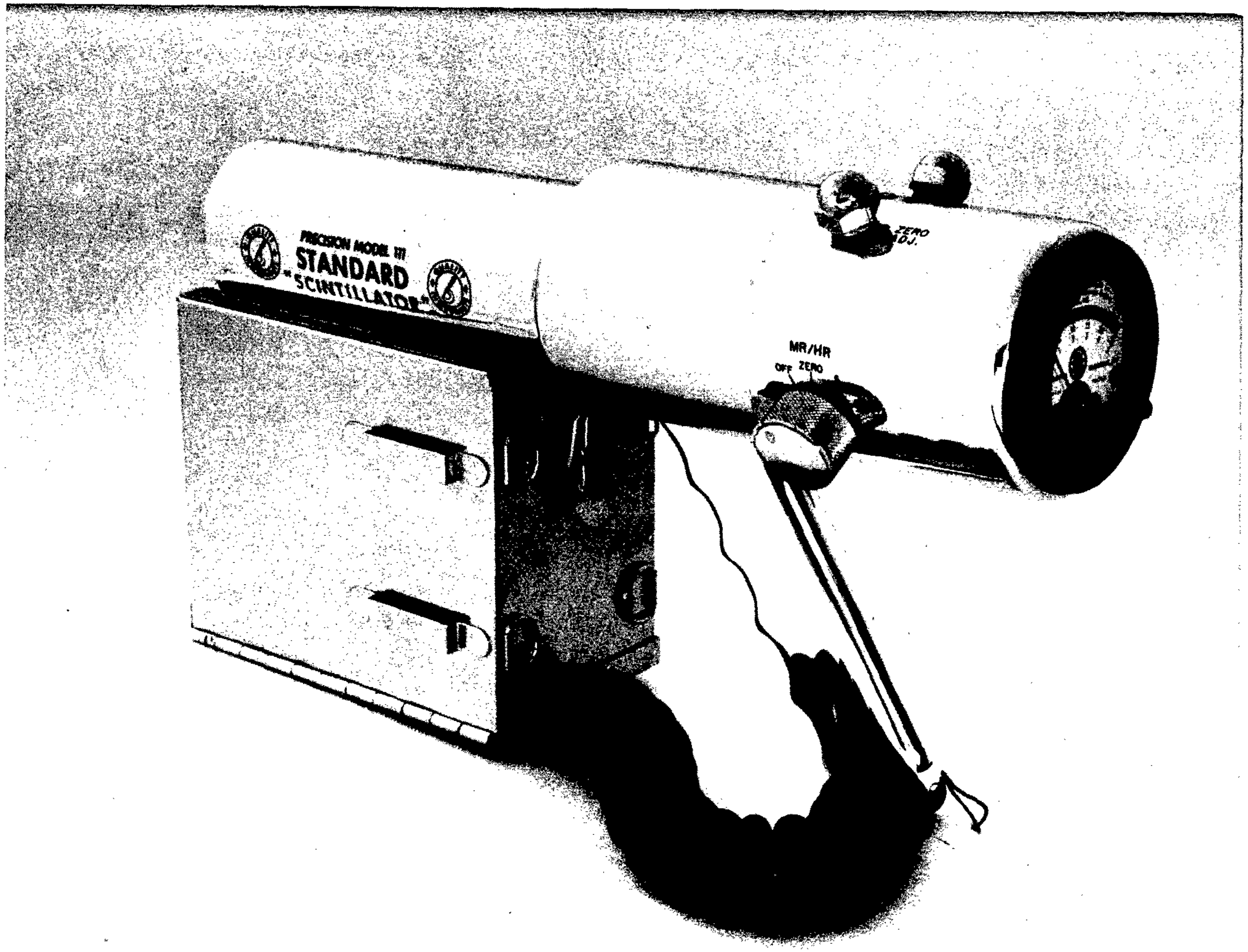


Fig. 2.12—Precision scintillator.

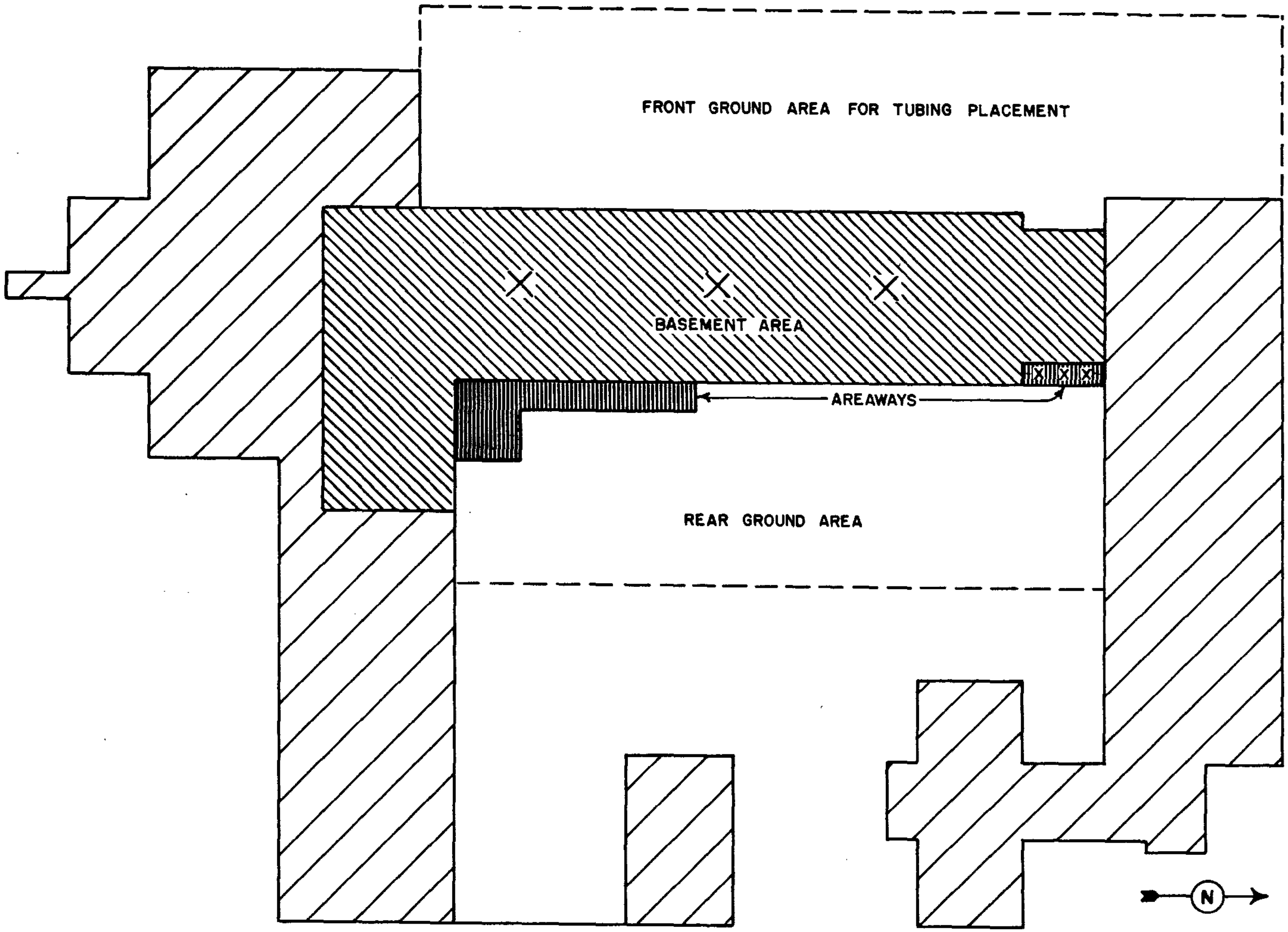


Fig. 2.13—Specific measurement areas at UCLA structure.

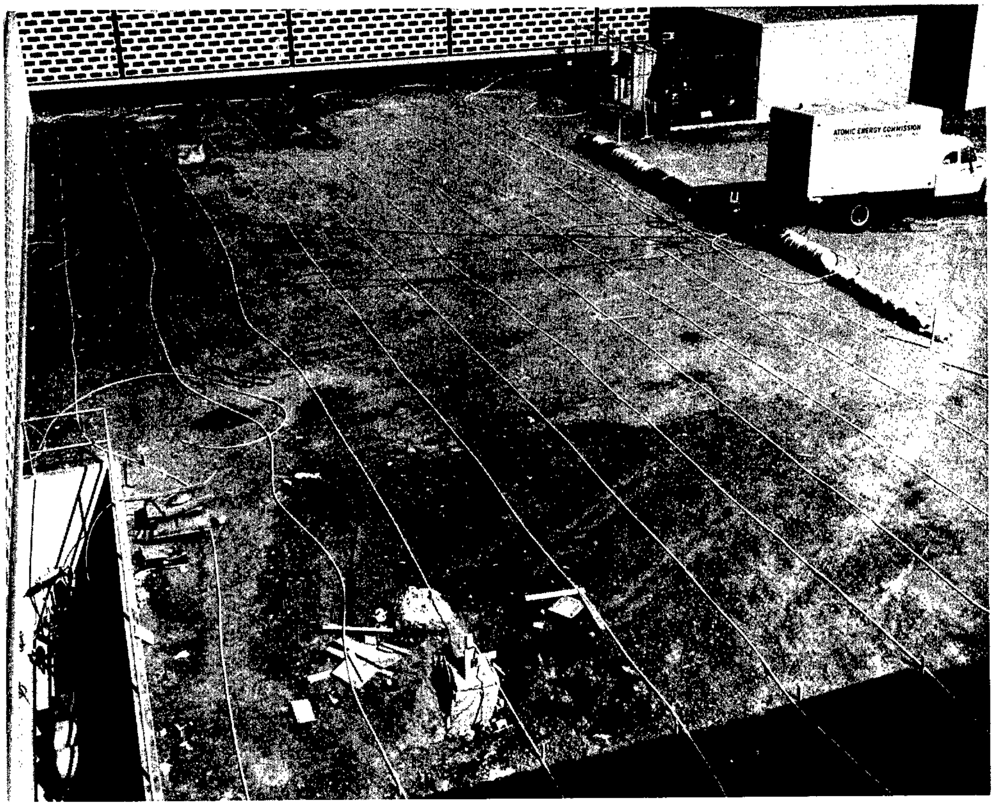


Fig. 2.14—Tubing layout in front of UCLA structure.

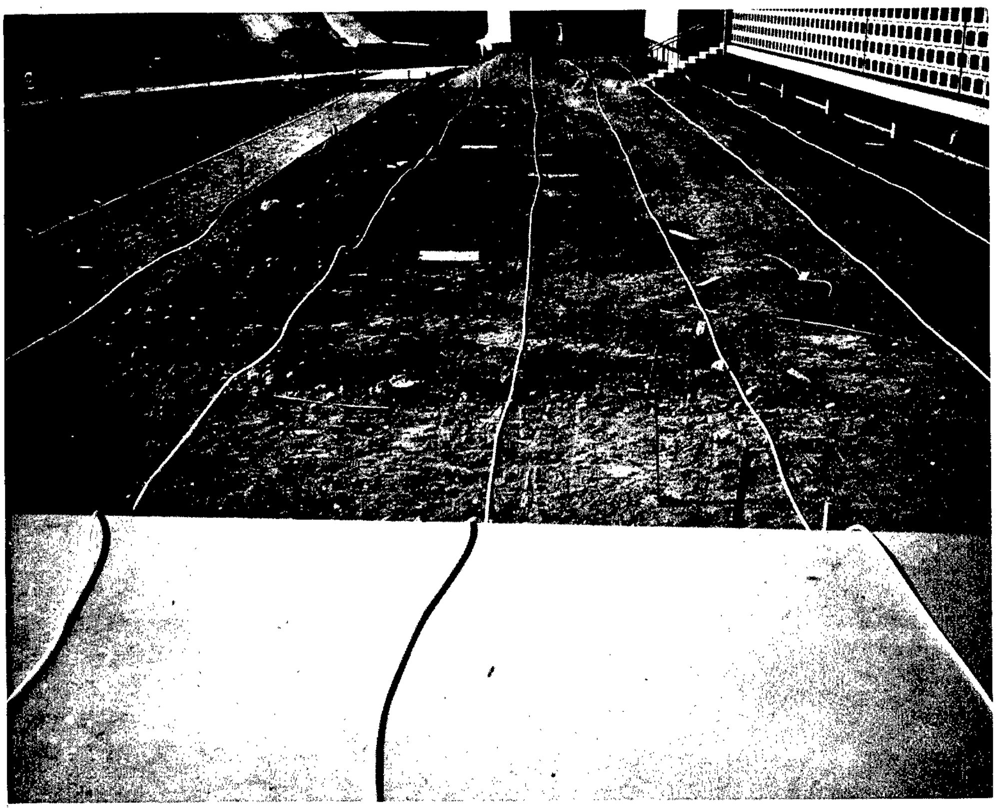


Fig. 2.15—Tubing layout in rear of UCLA structure.

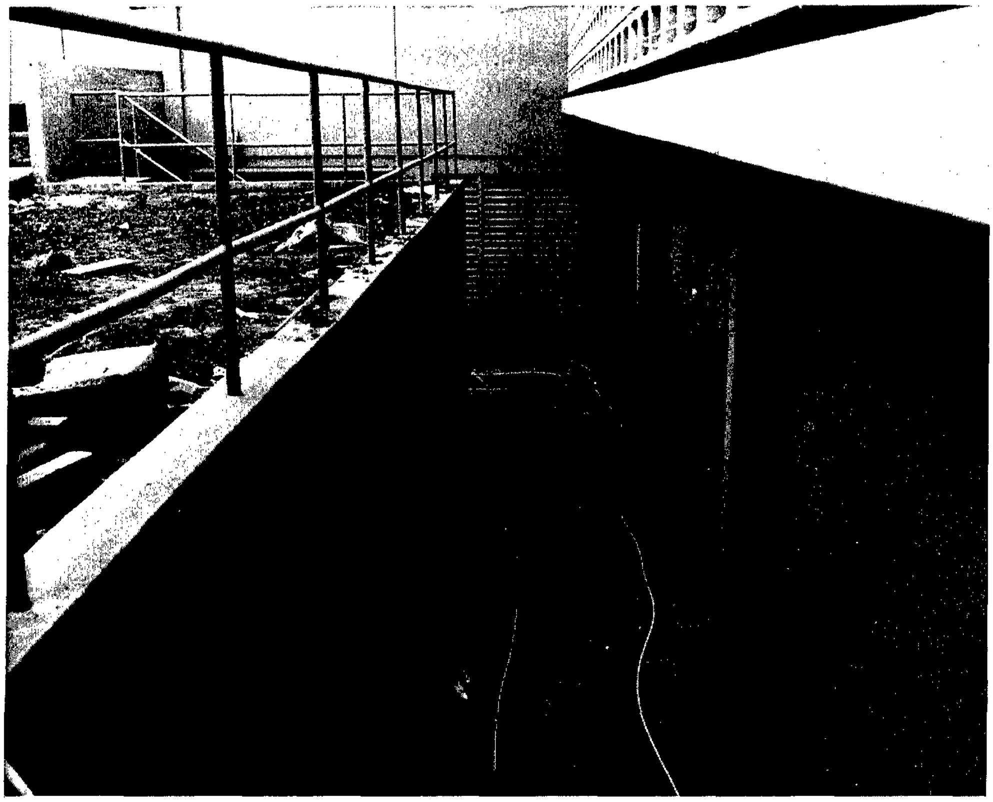


Fig. 2.16—Tubing layout in large areaway at UCLA structure.

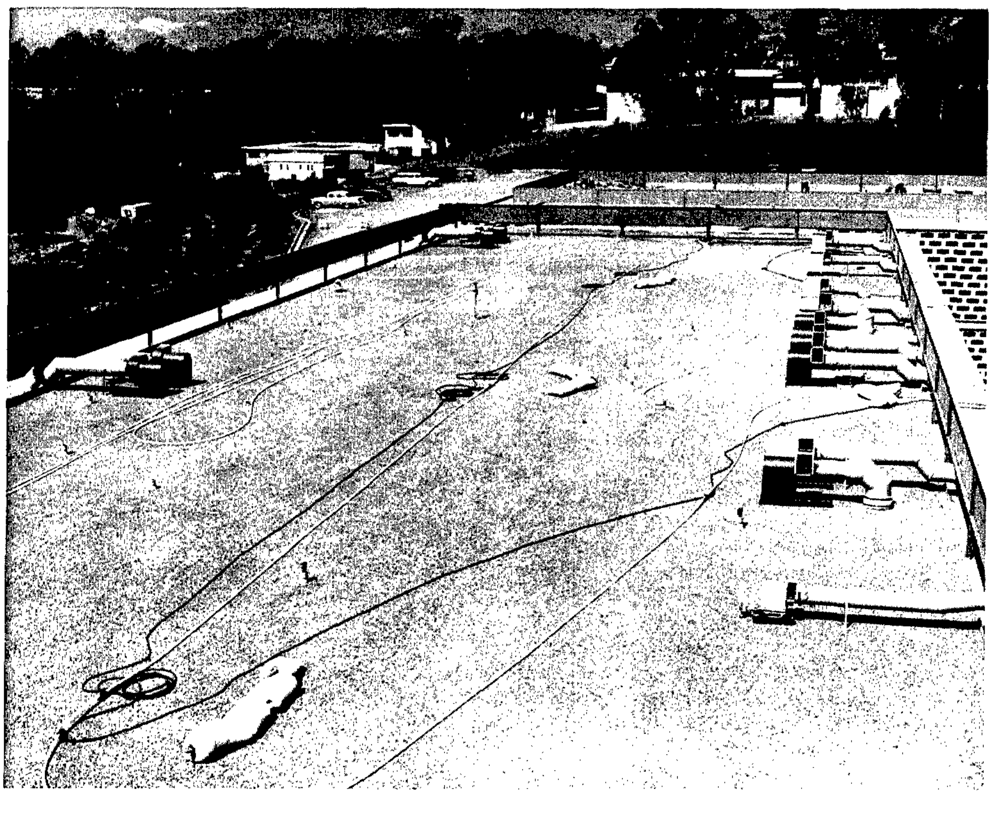


Fig. 2.17—Source positions on roof of UCLA structure.

Fig. 2.18—Detector positions in basement hallway of UCLA structure.

Fig. 2.19—Detector position in basement storage area of UCLA structure.

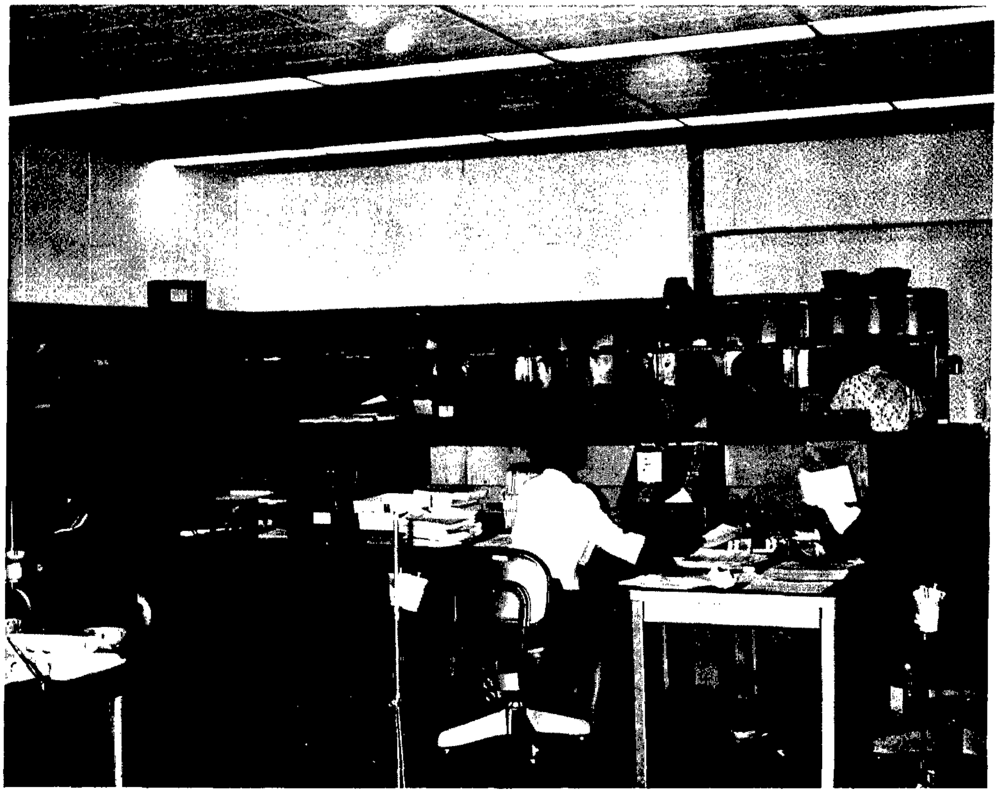


Fig. 2.20—Tubing layout on roof of house over fallout shelter.

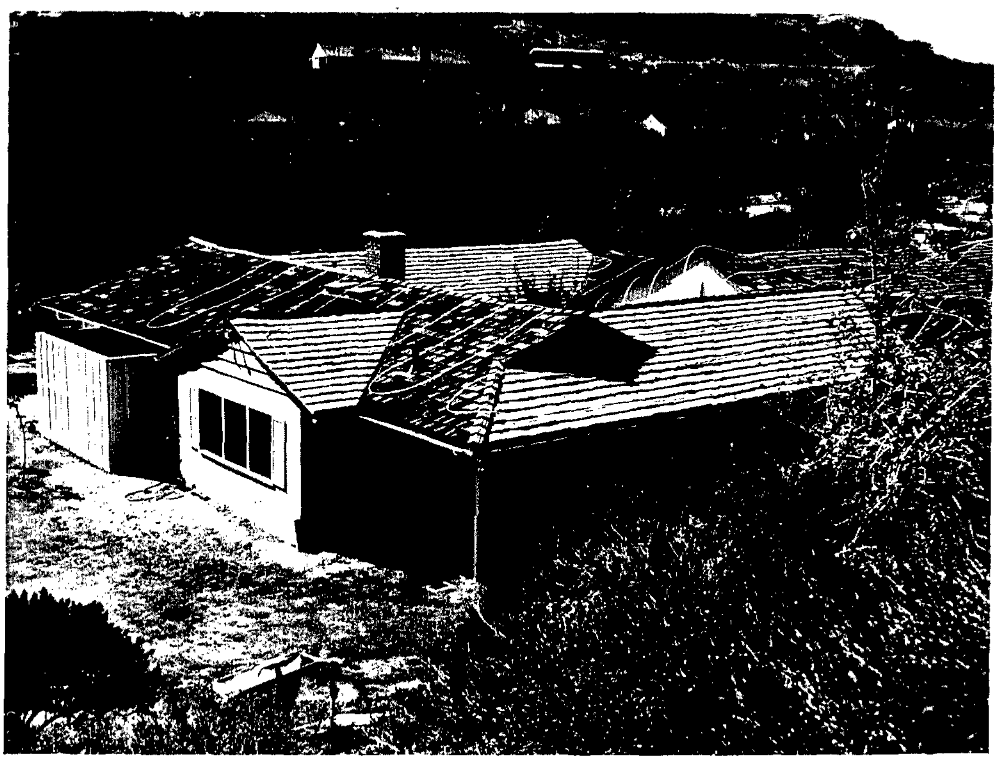


Fig. 2.21—Dosimeter positions in teletype room of Los Angeles Police Department building.

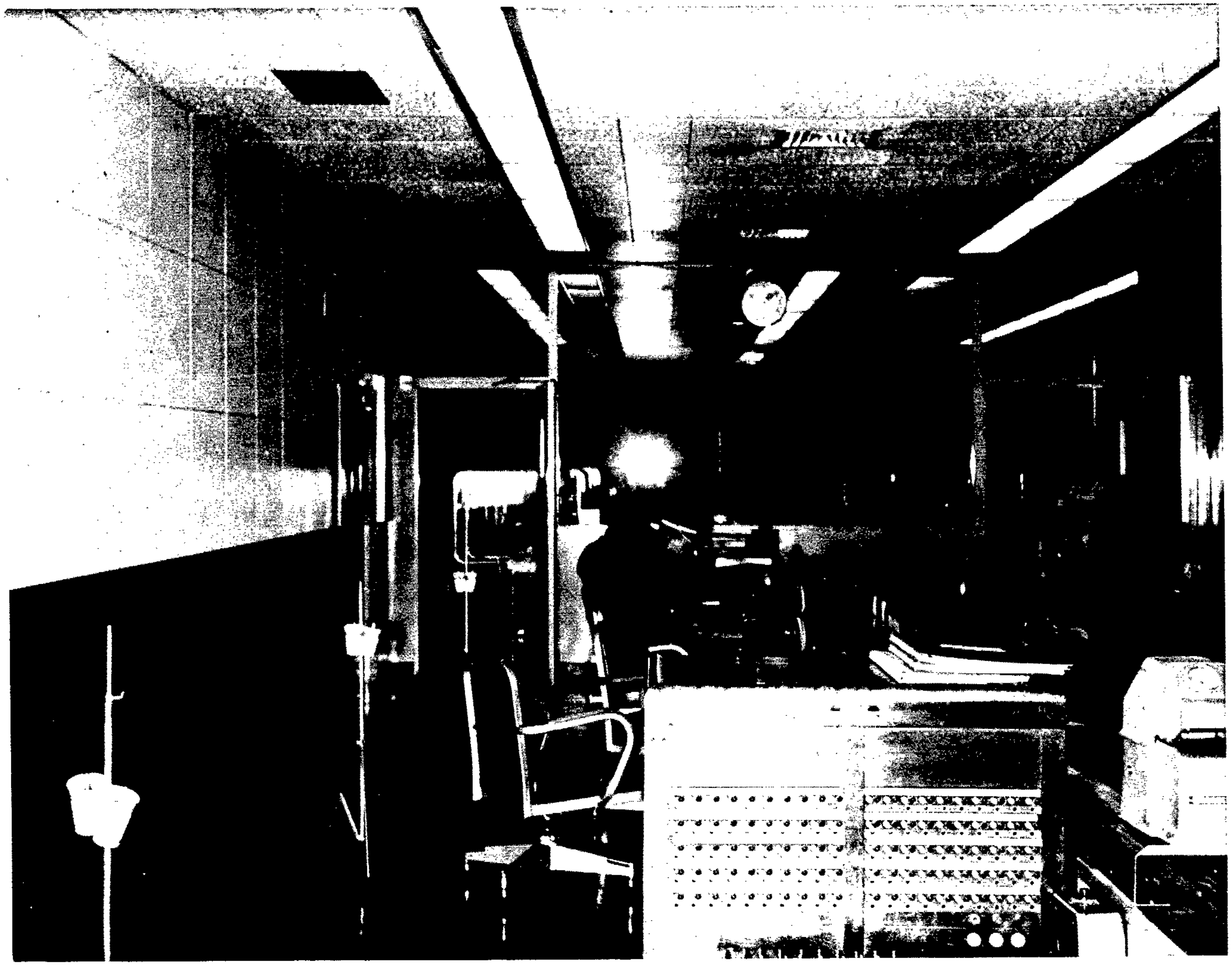


Fig. 2.22—Dosimeter positions in communications section of Los Angeles Police Department building.

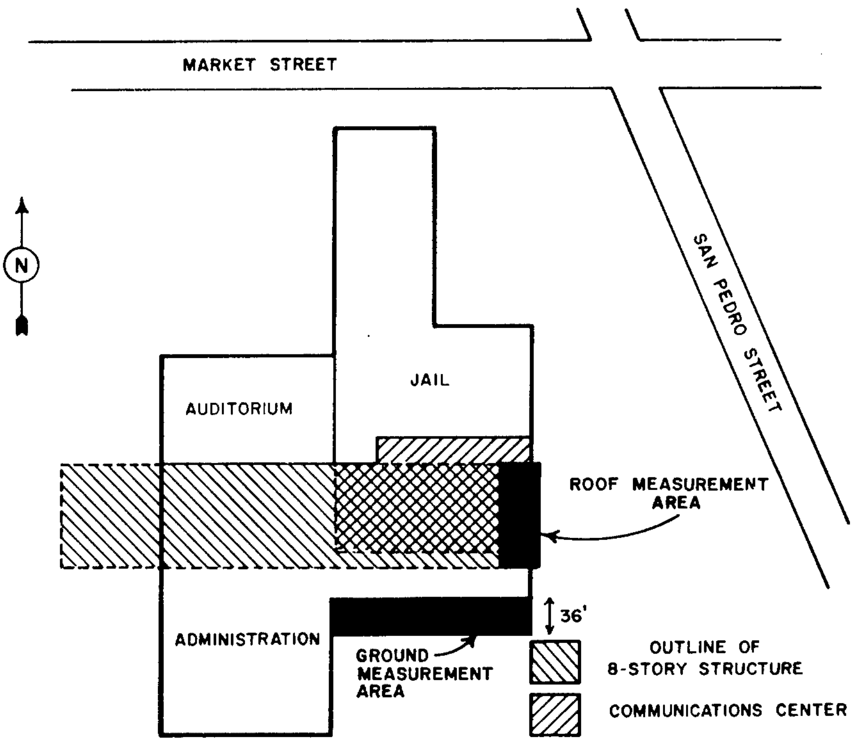


Fig. 2.23—Tubing placement locations at Los Angeles Police Department building.

Fig. 2.24—Tubing placement on parking lot at Los Angeles Police Department building.

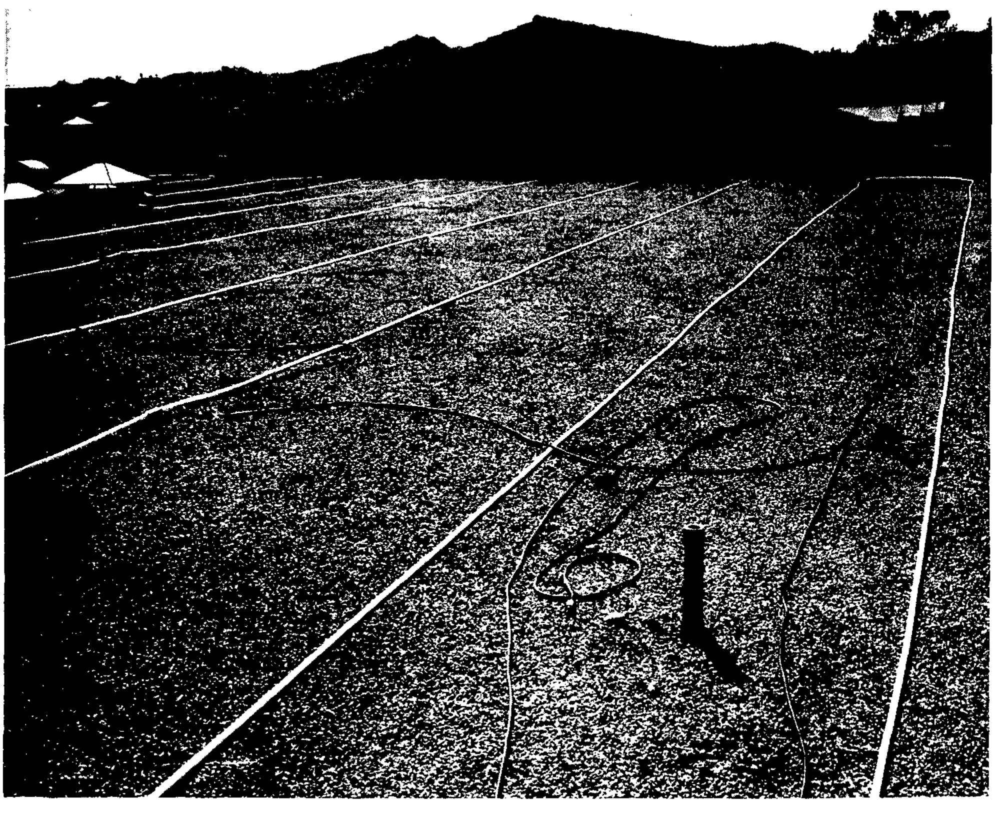


Fig. 2.25—Tubing placement on roof of North Hollywood High School classroom structure.

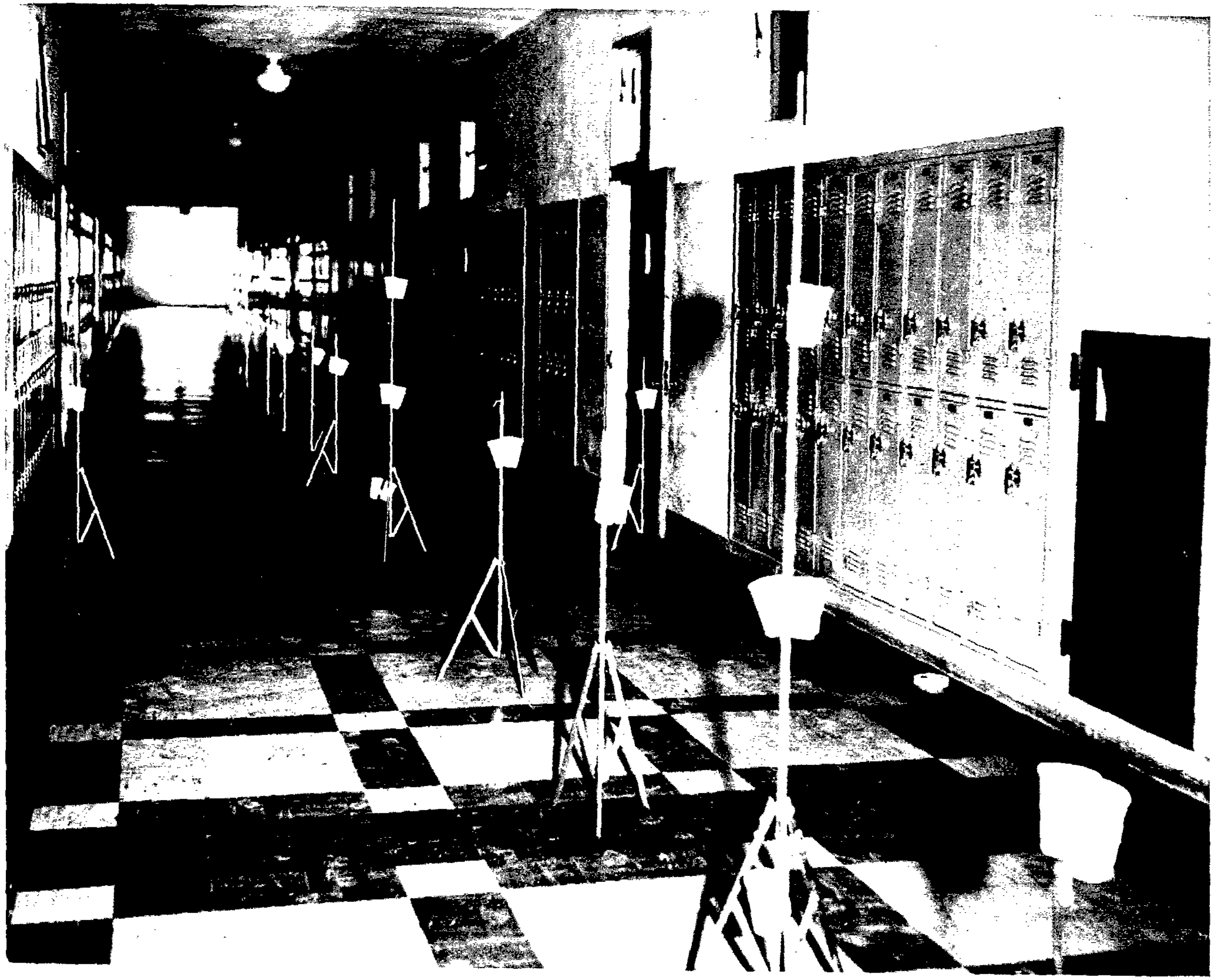


Fig. 2.26—Dosimeter positions in hallway of North Hollywood High School classroom structure.

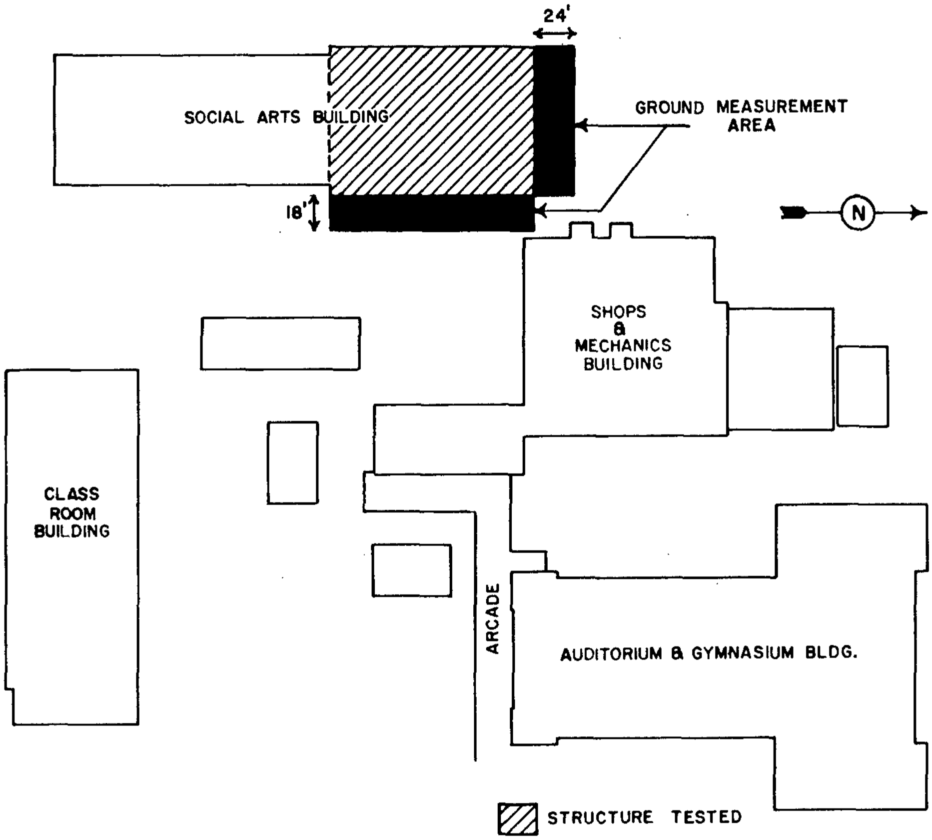


Fig. 2.27—Tubing locations at North Hollywood High School classroom structure.

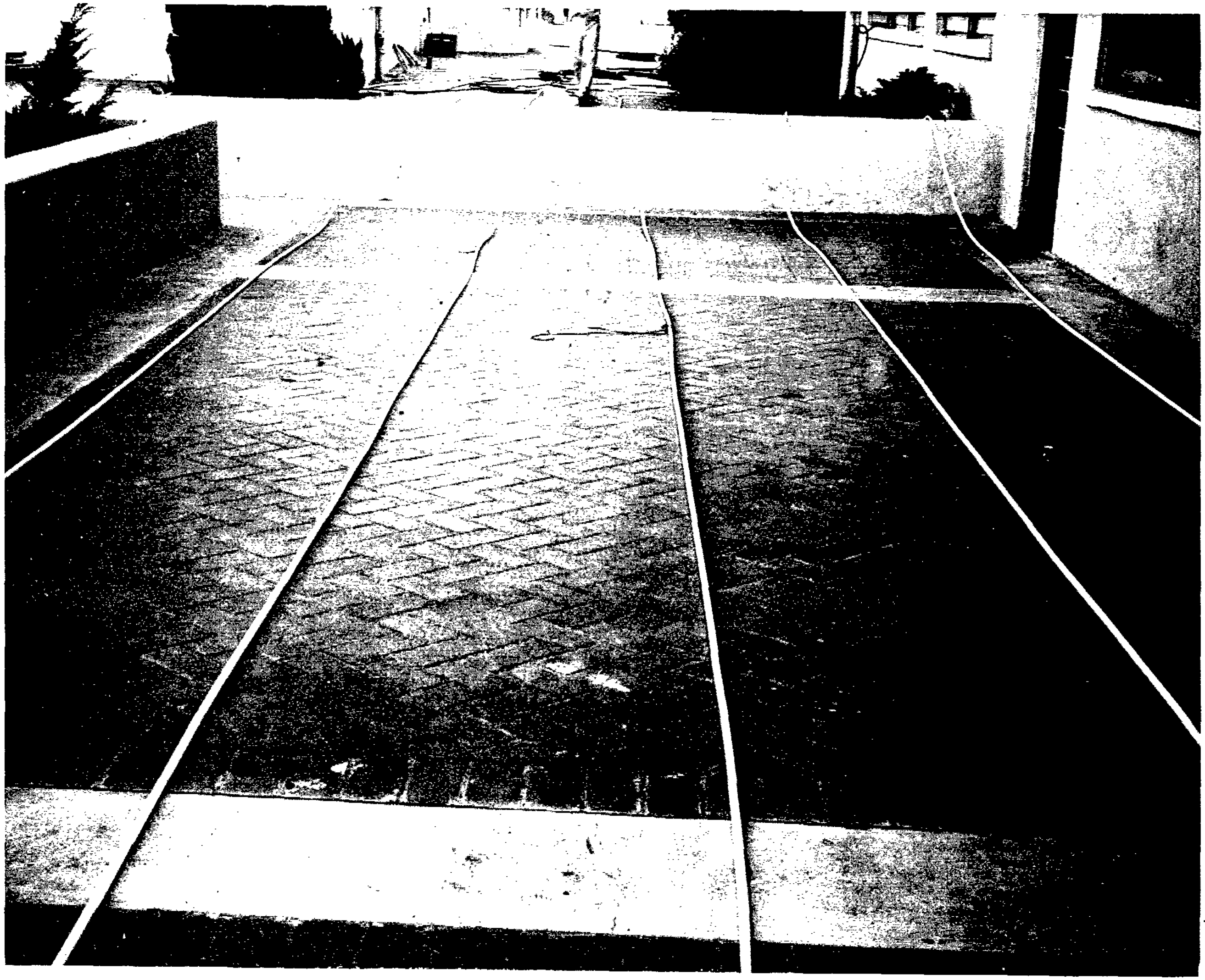


Fig. 2.28— Tubing placement on ground at North Hollywood High School classroom structure.

Chapter 3

PRESENTATION OF DATA

3.1 GENERAL

The data from each structure are presented separately. In most cases more than one dosimeter was used at each position. The readings from these dosimeters were averaged, and their average was corrected for temperature and calibration and then normalized to milliroentgen per hour per millicurie per square foot or milliroentgen per hour per curie, whichever was applicable. Dosimeter locations in the structures are indicated by numbers on floor plans, and the normalized dose rates at these positions are given in the tables. Data were taken at the 3-ft level at all positions, and occasional readings were taken at other levels. Where the dosimeter readings were extremely low, and therefore questionable, an indication is shown in the tables. Table 3.1 includes some of the information pertinent to each exposure at each structure.

3.2 UNIVERSITY OF CALIFORNIA AT LOS ANGELES STRUCTURE

A complete floor plan of the basement and partial floor plans of the first and second floors, together with dosimeter position numbers, are shown in Figs. 3.1 to 3.3. The normalized data at the 3-ft level are presented in Tables 3.2 to 3.4. A few readings were taken at other heights above the floor in the basement, but these did not show any great difference in dose rate and therefore are not presented.

Most of the data presented in Table 3.2 were taken from measurements by the low-range ionization chambers (10-mr full scale), and those in Table 3.3, from measurements by the high-range chambers (200-mr full scale). Most of the data from point sources on the roof were taken with the Precision scintillator.

3.3 HOME FALLOUT SHELTER

Dosimeter positions in the fallout shelter are shown in Fig. 3.4; position No. 19 was below the stairs. Four dosimeters were placed at the 3-ft level at each position inside the shelter. The 16.5-curie source was used for an exposure of 1 hr. The readings on the dosimeters inside the shelter proper were hardly detectable, 0.1 mr (see Table 3.5).

The source was stopped on the roof of the house directly above the shelter proper; and the dose rate measured by the Precision scintillator at position No. 16 was 0.1 mr/hr. Readings in the shelter with the source stopped at other locations were much lower and therefore are not presented.

3.4 LOS ANGELES POLICE DEPARTMENT BUILDING

Floor plans of the communications section of the police building, along with dosimeter locations, are presented in Fig. 3.5. Data taken when the tubing was placed on the roof appear in Table 3.6. The exact location of the teletype room in relation to the roof above it was not known at the time of the measurements; otherwise, a larger area of the roof would have been used.

The 16.5-curie source was used with the tubing distributed on the upstairs parking lot. Radiation levels inside the communications section were too low to measure with the ionization chambers. An indication of the dose rates was obtained by pumping the source through the tubing slowly and recording the dose rate at position No. 3 every 15 sec with the Precision scintillator. Fifty-four readings were made. The readings varied from 0.02 to 0.3 mr/hr, with an average of 0.08 mr/hr, or approximately 0.02 mr/hr/mc/sq ft.

3.5 TYPICAL CLASSROOM AT NORTH HOLLYWOOD HIGH SCHOOL

Measurements were made only on the first floor of this structure. Floor plans and dosimeter positions appear in Fig. 3.6, and the data from all three exposures appear in Table 3.7. Operational limitations were such that larger areas, larger sources, or longer exposure times could not be used. However, the data obtained were useful as guide lines in estimating the protection factors.

TABLE 3.1—EXPOSURE PARAMETERS

Structure	Description	Location	Exposure time, hr	Av. temp., °F	Av. pressure, in. Hg	Area, sq ft	Source strength, curies
UCLA	Ground area	Large areaway	0.492	73	29.9	882	16.5
UCLA	Ground point	Small areaway	1.000	72	29.9	216	13.5
UCLA	Ground area	West side (front)	1.170	73	30.0	18,000	266
UCLA	Ground area	East side (rear)	1.043	73	29.9	11,210	266
UCLA	Roof point	Point source on roof		73	29.9		266
UCLA	Filter point	Near filters in fan room					13.5
Fallout shelter	Roof area	Tubing over most of roof	1.000	72	30.0	4,000	16.5
Los Angeles Police Department	Ground area	Upstairs parking lot		74	29.9	5,040	16.5
Los Angeles Police Department	Roof area	Roof over teletype room	0.325	74	29.9	2,448	16.5
Classroom	Roof area	Roof over east end	0.110	75	30.0	6,950	266
Classroom	Ground area	North side	0.109	75	30.0	1,700	16.5
Classroom	Ground area	East side	0.884	75	30.0	1,760	16.5

TABLE 3.2—DATA FROM BASEMENT OF UCLA STRUCTURE

Position	Large areaway exposure, mr/hr/mc/sq ft	Small areaway exposure, mr/hr/mc/sq ft	West side (front) ground exposure, mr/hr/mc/sq ft	East side (rear) ground exposure, mr/hr/mc/sq ft	Source near filter system,* mr/hr/curie
1	0†		0.021†		0.1
2	0†		0.007†	0†	0.1
3	0†		0.007†	0†	0.2
4	0.01†		0.021†	0.005†	0.07
5	0.03†		0.062	0†	0.3
6	0.04†		0.048	0.005†	0.3
7	0.08		0.086	0.009†	0.7
8	0.14		0.083	0.005†	1
9	1.1		0.13	0.019†	7
10	0.30		0.15	0.034	40
11	0.31		0.19	0.062	150
12	0.24		0.16	0.048	
13	0.13		0.23	0.034	
14	0.90		0.17	0.067	60
15	1.8		0.17	0.096	90
16	5.1		0.11	0.14	70
17	3.2		0.090	0.24	
18	1.7		0.12	0.21	
19	0.35		0.14	0.12	
20	11		0.034†	0.24	
21	0.41		0.16	0.048	9
22	0.38		0.13	0.096	1
23	0.26		0.16	0.098	0.8
24	0.17		0.19	0.12	0.3
25	0.15		0.26	0.067	0.2
26	0.04†			0.024†	0.2
27	0.58		0.15	0.24	1
28	9.2			0.096	0.3
29	8.7			0.14	2
30	1.4		0.14	0.25	2
31	0.82		0.10	0.22	3
32	1.2		0.10	0.15	8
33	5.4		0.083	0.14	5
34	0.08		0.18	0.12	0.2
35	0.10		0.28	0.086	0.2
36	0.10		0.26	0.062	0.1
37	0.01†		0.16	0.009†	0.04
38			0.10	0.034	0.06
39	0.04†		0.10	0.034	0.1
40			0.17	0.21	0.3
41	0.06		0.12	0.24	0.2
42			0.090	0.18	0.1
43			0.055	0.096	0.1
44			0.14	0.30	0.1
45	0.03†		0.16	0.053	0.2
46	0.05†		0.13	0.12	0.1
47	0†		0.18	0.062	0.1
48	0†		0.22	0.11	0.07
49	0†		0.47	0.034	
50	0†		0.32	0.086	0.04

TABLE 3.2—DATA FROM BASEMENT OF UCLA STRUCTURE (Continued)

Position	Large areaway exposure, mr/hr/mc/sq ft	Small areaway exposure, mr/hr/mc/sq ft	West side (front) ground exposure, mr/hr/mc/sq ft	East side (rear) ground exposure, mr/hr/mc/sq ft	Source near filter system,* mr/hr/curie
51	0†	0.002†	0.43	0.058	
52	0†	0.004†	0.30	0.038	
53	0†		0.16	0.029	
54	0†		0.096	0.25	0.02
55	0†	0.12	0.069	0.28	0.02
56	0†	0.030	0.083	0.26	0.04
57	0†	0.008†	0.12	0.28	0.04
58	0†	0.002†	0.32	0.014†	0.02
59	0†	0.002†	0.58	0.034	
60	0†	0.004†	0.53	0.048	
61	0†	0.009†	0.31	0.058	0.02
62	0†	0.018	0.23	0.11	
63	0†	0.004†	0.49	0.062	
64	0†	0.006†	0.42	0.048	
65	0†	0.022	0.20	0.094	
66	0†	0.049	0.069	0.019†	
67	0†		0.014†	0.038	
68	0†	0.057	0.10	0.14	
69	0†	6.8		0.24	
70	0†	0.28	0.041	0.43	
71	0†	3.7		0.11	
72	0†	27	0.014†	0.26	
73	0†	23			
74	0†	5.0	0.12	0.26	
75	0†		0.014†	0.014†	
76	0†			0.009†	
77	2.1		0.010†	0.053	0.04
78	0.38		0.014†	0.007	0.01
79	0.030†		0.007†	0†	0.003
80	4.2		0.014†	0.12	0.1
81	15		0.014†	0.34	2
82	38		0.028†	0.41	0.1
83	0†		0.007†	0.014†	0.04
84	5.4		0.021†	0.19	0.07
85	0.58		0.007†	0.009†	0.03
86	0.040†		0.16		0.2

*Data taken with survey meter (T1B) and Precision scintillator. Results given only to one significant figure.

†Low-range chambers read less than 0.5 mr.

TABLE 3.3— DATA FROM FIRST AND SECOND FLOORS OF UCLA STRUCTURE

Position	West side (front) ground exposure, mr/hr/mc/sq ft	East side (rear) ground exposure, mr/hr/mc/sq ft	Position	West side (front) ground exposure, mr/hr/mc/sq ft	East side (rear) ground exposure, mr/hr/mc/sq ft
101	0.52	2.9	206		2.1
102		6.7	207	0.06	2.2
103	0.14	14	208		1.1
104	0.10	14	209	0.03	2.6
105	0.25	1.9	210	0.03	0.38*
106	17	0.13	211	0.19	0.77
107	21	0.14	212	0.06	1.0
108	9.6	0.17	213		1.3
109	6.9	0.19	214	0.06	3.5
110	0.58	1.9	215	0.08	3.1
111		4.8	216		1.3
112	0.18	15	217	0.03	3.3
113	0.19	11	218	0.03	0.53
114		3.8	219	1.7	0.07
115	0.50	2.2	220	1.6	0.05
116	4.5	0.26	221	6.2	0.04
117	16	0.12	222	6.5	0.03
118	18	0.08	223	5.3	0.02
119	2.9		224	1.2	0.02
120	6.2	0.41	225	1.6	0.05
121	17	0.10	226	3.9	0.02
122	17	0.07	227	0.69	0.27
123	2.7	0.58	228	0.55	0.14
124	2.3	0.19	229	0.34	0.16
125	2.5	0.96	230		0.06
126	2.5	0.35			
201	0.10	0.43*			
202	0.05	1.8			
203	0.15	0.48*			
204	0.15	0.48*			
205		1.2			

*High-range chambers read less than 10 mr.

TABLE 3.4—DATA FROM POINT SOURCE ON ROOF OF UCLA STRUCTURE

Position	Source in south position, mr/hr/curie ($\times 10^{-4}$)	Source in center position, mr/hr/curie ($\times 10^{-4}$)	Source in north position, mr/hr/curie ($\times 10^{-4}$)
1	0.4		
4	0.8		
5	2	0.4	
8	6		
9	20		
10	30	0.8	
11	30	2	
14	20	10	
21			
22	9	20	
23	4	50	
24	3	50	
34	0.8	10	2
44	0		
47	0	0.4	10
48	0		20
50	0		20
58			10
61			5
62			1
65			0.4
66			0.4
81	50	150	
82	90	150	
84	8	50	
101			30
102			40
103			60
104			30
105			6
106			150
107			90
108			100
109			100
110			8
111			4
112			50
113			40
114			20
115			6
116			10
117			50
118			30
119			10
120			30
121			40
122			30
123	3	10	1,000
124	2	5	700
125	2	5	150
126	2	5	70
Directly under source (first floor)	2,000	1,500	1,000
25 ft horizontally from source (first floor)	100	80	
Directly under source (second floor)	15,000		
25 ft horizontally from source (second floor)	1,000		

TABLE 3.5—DATA FROM FALLOUT SHELTER

Position	Data, mr/hr/mc/sq ft
8 (lying on stairs)	32
9 (lying on stairs)	14
10 (lying on stairs)	5.8
11	1.9
13	0.06*
14	0.03*
15	0.03*
16	0.03*
17	0.03*
18	0.03*
19 (under stairway)	0.13

*Low-range chambers read less than 0.5 mr.

TABLE 3.6—DATA FROM ROOF EXPOSURE AT LOS ANGELES POLICE DEPARTMENT BUILDING

Position	Data, mr/hr/mc/sq ft
1	0.027*
2	0.081*
3	0.11*
4	0.11*
5	0.22*
6	0.27
7	0.054*
8	0.081*
9	1.0
10	0.86
11	0.81
12	0.51
13	0.22*
14	0.11*
15	0.11*
16	0.19*
17	0.16*
18	1.6
19	5.0
20	3.5
21	4.8
22	5.2
23	2.9
24	4.2
25	3.2

*Low-range chambers read less than 0.5 mr.

TABLE 3.7 — DATA FROM FIRST FLOOR OF NORTH HOLLYWOOD HIGH SCHOOL CLASSROOM STRUCTURE

	Roof exposure, mr/hr/mc/sq ft			East ground exposure, mr/hr/mc/sq ft			North ground exposure, mr/hr/mc/sq ft		
Position	1 ft	3 ft	5 ft	1 ft	3 ft	5 ft	1 ft	3 ft	5 ft
1		0.59			0.058*			25	
2		0.87			0.043*			11	
3	0.73	0.82	0.87	0.58*	0.058*	0.79	6.0	7.4	7.7
4		0.86			0.10			5.0	
5		0.93			0.11			3.2	
6		0.77			0.079			1.8	
7	0.87	0.93	0.96	0.11	0.14	0.18	1.0	1.8	2.0
8		0.82			0.12			1.9	
9		0.76			0.029*			0.62	
10		0.75			1.8				
11		0.75			4.3				
12		0.65			10				
13		0.93			0.63				
14		1.02			0.86				
15		0.85			1.3				
16		0.96			0.19			1.1	
17		0.95			0.17			0.90	
18		0.85			0.61			0.79	
19		0.79			0.35			0.56	
20	0.84	0.86	0.98	0.18	0.20	0.23		0.34*	
21		1.11			0.036*				
22		0.59			0.37			0.23*	
23		0.85			1.5				
24		0.80			0.079				
25		0.62			0.014*				
26								0.68	
27								0.90	
28								0.40*	
29								0.28*	

*Low-range chambers read less than 0.5 mr.

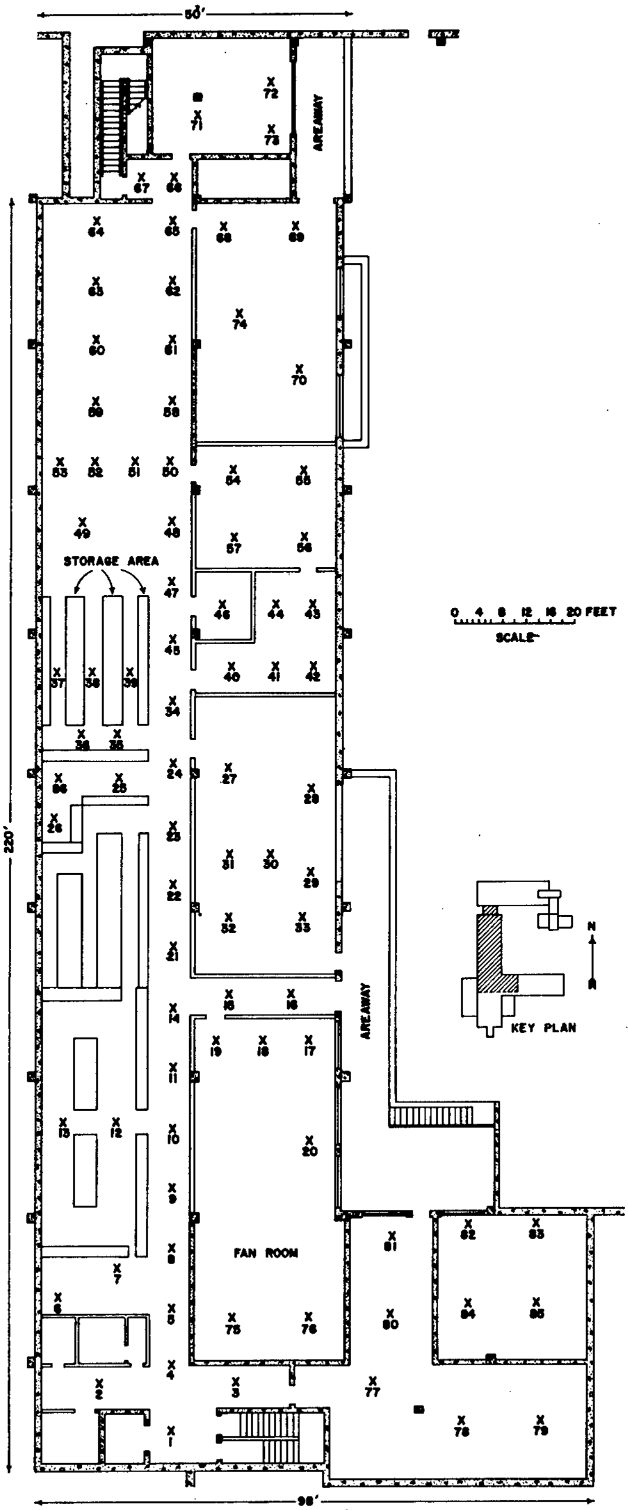


Fig. 3.1—Floor plan of basement of UCLA structure with detector positions indicated.

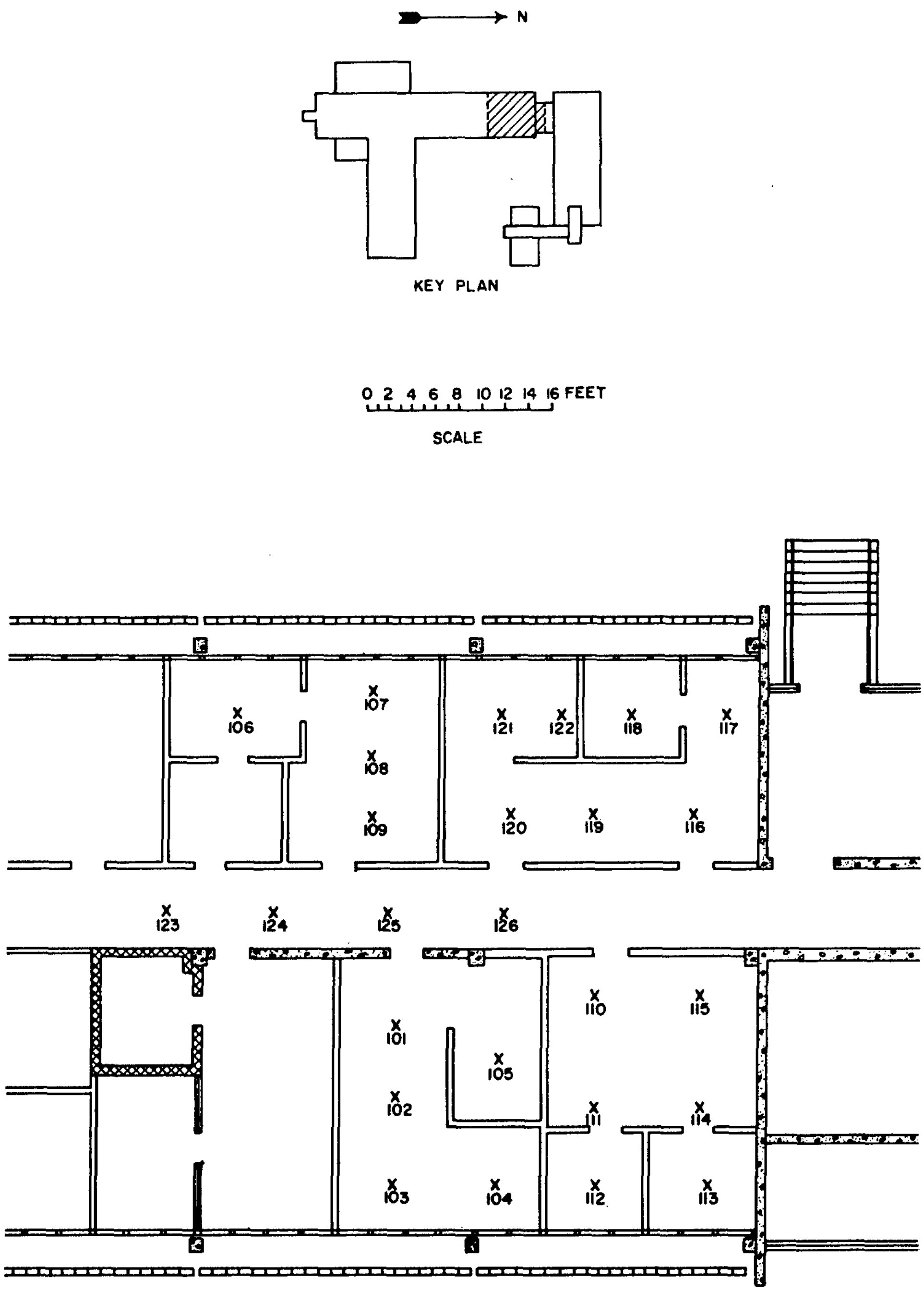


Fig. 3.2—First-floor plan of UCLA structure with detector positions indicated.

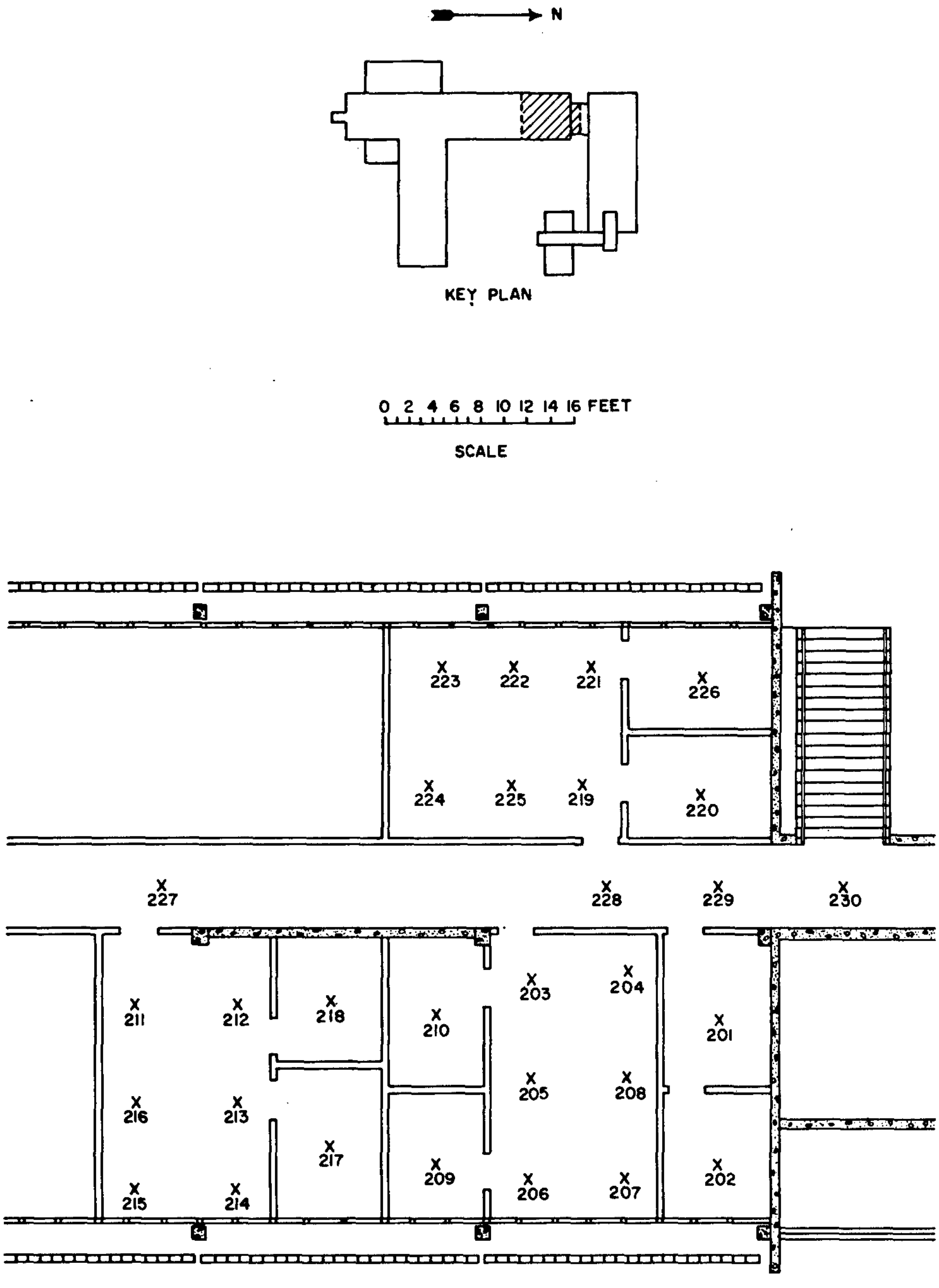


Fig. 3.3—Second-floor plan of UCLA structure with detector positions indicated.

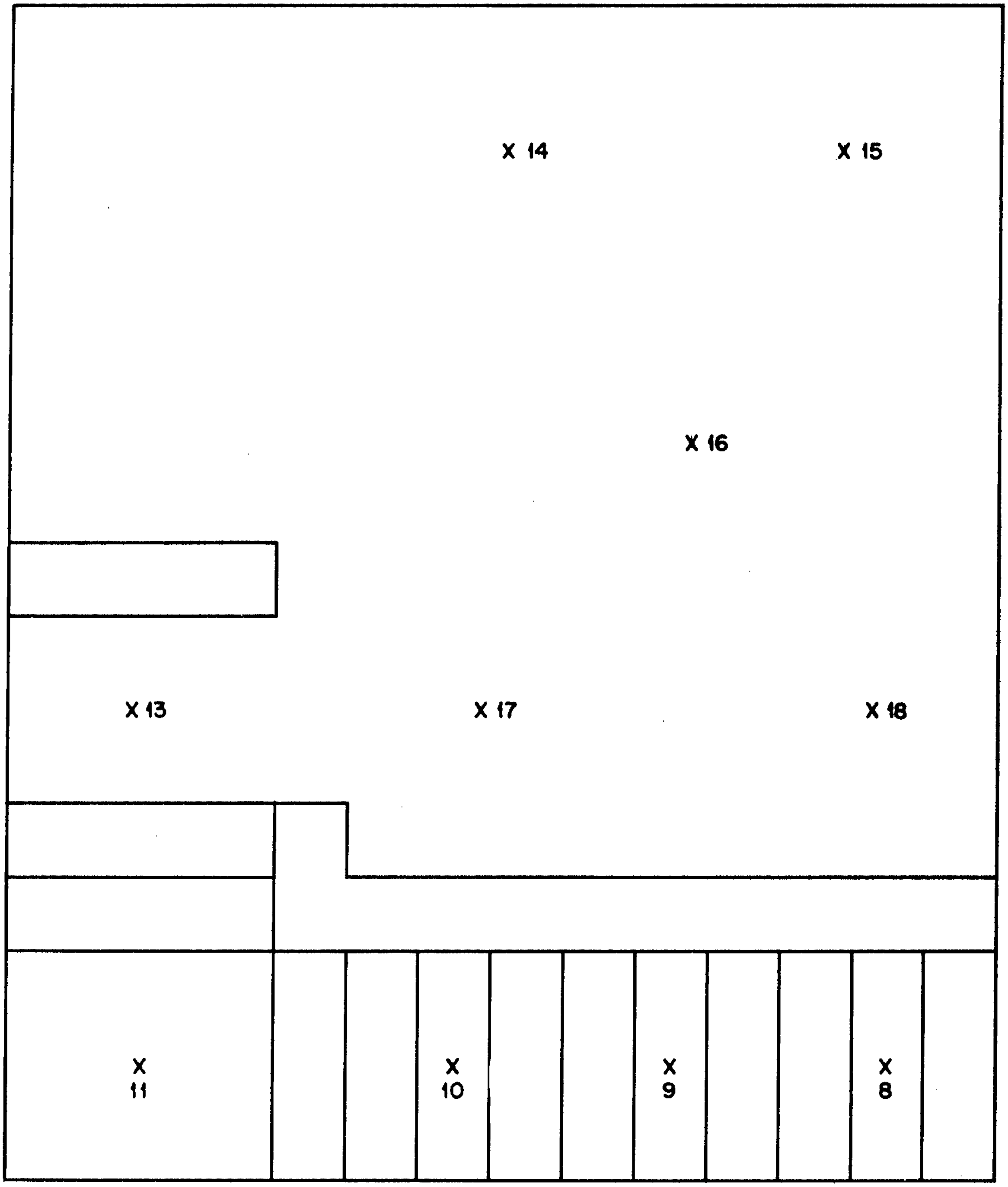


Fig. 3.4—Approximate floor plan of home fallout shelter showing detector positions.

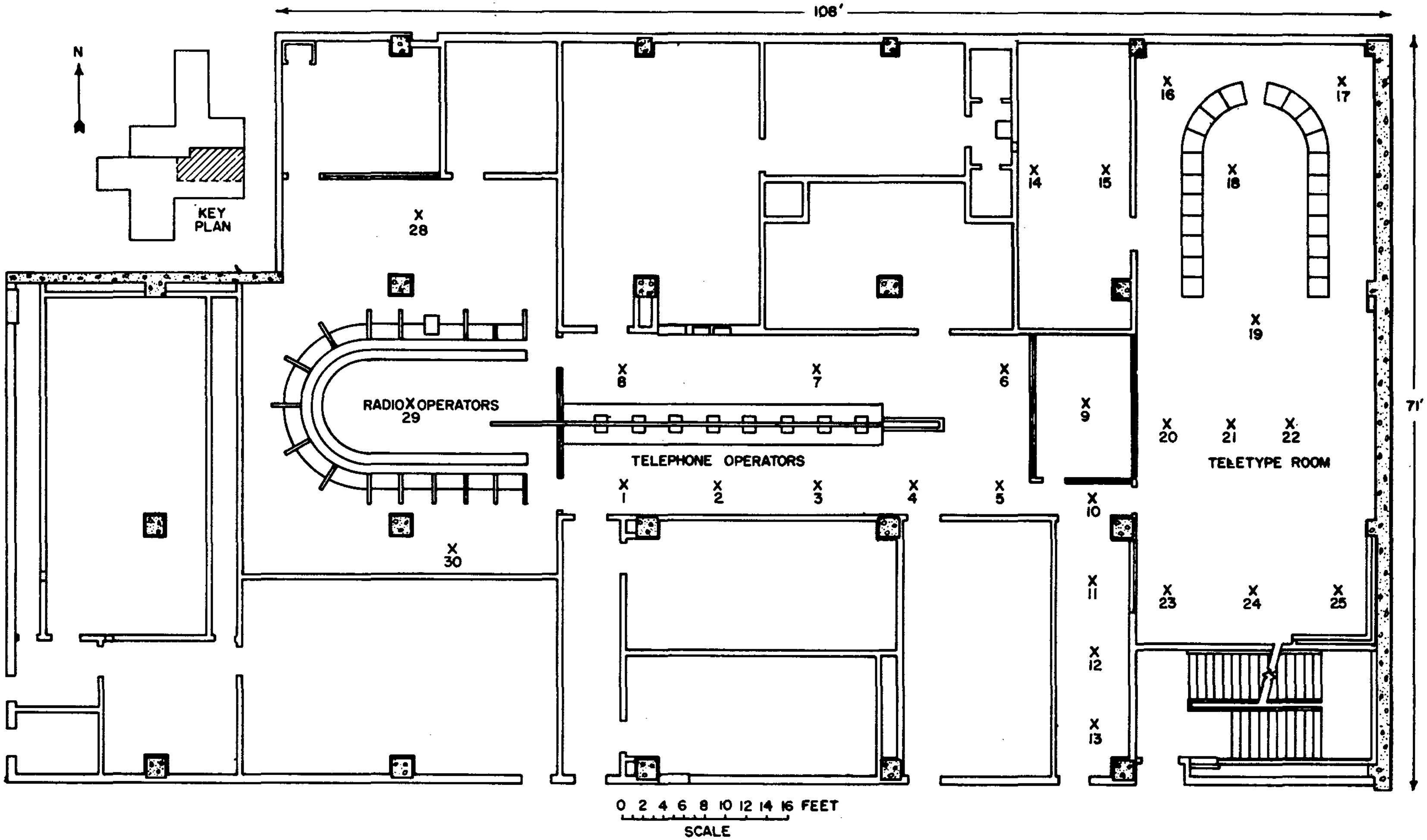


Fig. 3.5—Floor plan of communications section of Los Angeles Police Department building showing detector positions.

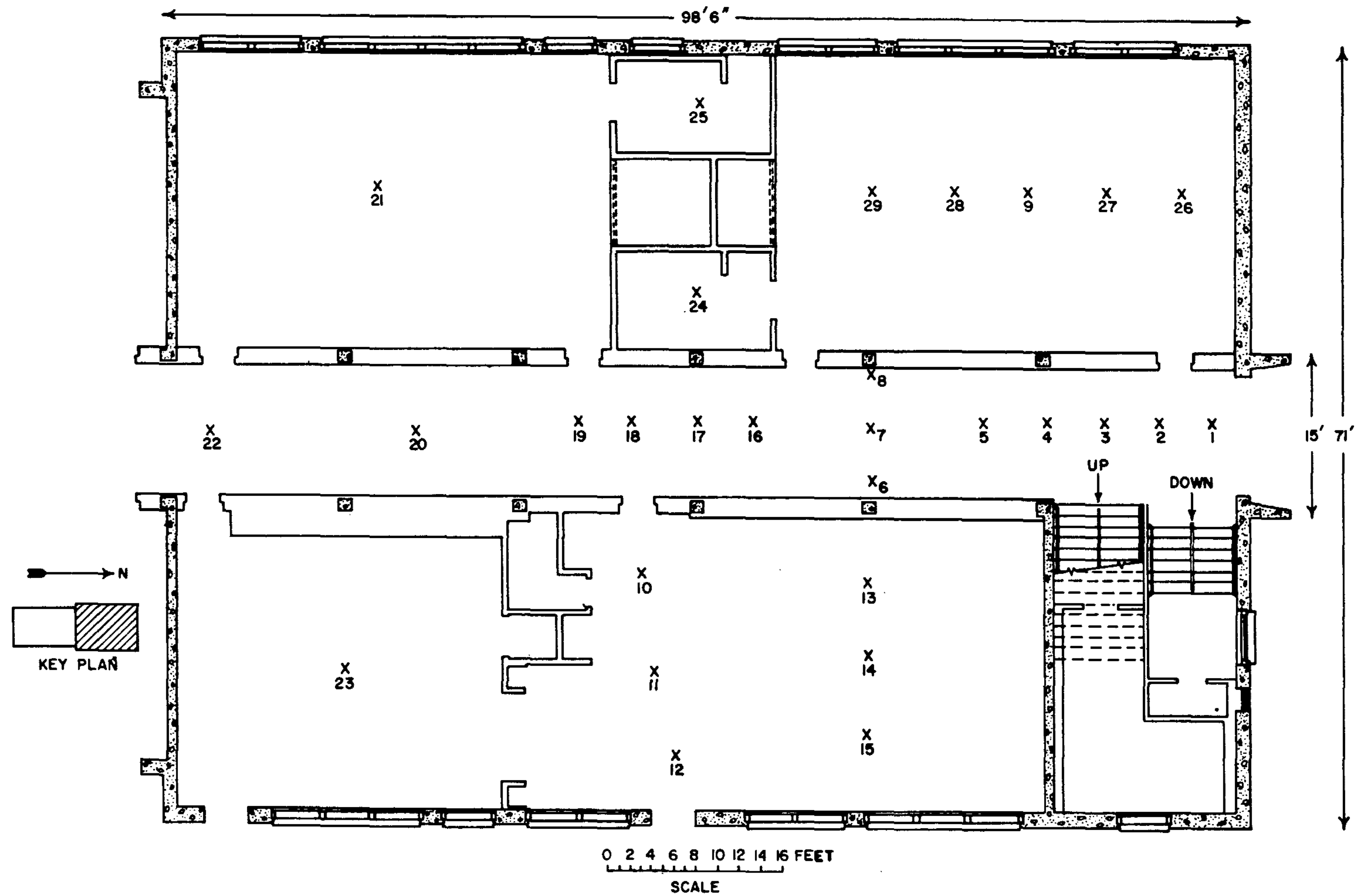


Fig. 3.6—First-floor plan of North Hollywood High School classroom structure showing detector positions.

Chapter 4

ANALYSIS AND CONCLUSIONS

4.1 GENERAL

To evaluate the protective qualities of a structure and to give this protection quantitative expression, one uses the term "protection factor." This factor is a number that indicates the protective value of a structure and provides a measure of how much less the radiation level would be inside the structure than outside in an unprotected area. In technical terms it is the ratio of the exposure dose rate 3 ft above a smooth infinite plane that is uniformly contaminated with radioactive material to the dose rate at a specific point in question, assuming the same source distribution. Accordingly,

$$\text{Protection factor} = \frac{D_\infty}{D} \tag{4.1}$$

where D_∞ is the total infinite-plane dose rate and D is the dose rate at the point in question.

The value of the total infinite-plane dose rate has been evaluated in the literature[1–4] and is estimated[4] to be 500 mr/hr when the radioactive material (Co^{60}) is distributed to a source density of 1 mc/sq ft.

The use of Co^{60} in simulating fallout radiation for shielding studies has been discussed by C. Eisenhauer.[2] The protection factors for radiation from fission products and Co^{60} gamma radiation should compare quite closely at early times after a detonation.

It would be necessary to simulate fallout radiation on the structure and on the ground surrounding the structure out to an infinite distance to accurately measure a protection factor. Since this is impractical, simulation in these experiments was limited to the immediate vicinity of the structures where the results would be most helpful in determining the protection factors. The contribution from those areas not simulated was analytically estimated by theoretical calculations and by the use of experimental data as guide lines.

4.2 NORMALIZATION AND CALCULATIONS

It was convenient to normalize all the experimental data from a particular exposure to a standard-source density so that the results could be evaluated properly. After the dosimeter readings were corrected for background, temperature, and calibration, they were then normalized by multiplying the corrected readings (D_c, in milliroentgens) by the total area (A, in square feet) over which the tubing was distributed and dividing by the exposure time (T, in hours) and by the source strength (S, in millicuries). Accordingly,

$$\text{Normalized dose rate, mr/hr/mc/sq ft} = \frac{D_c \times A}{T \times S} \tag{4.2}$$

The resulting dose rate at a particular point is then the same as it would be if the same area were contaminated by Co^{60} to a source density of 1 mc/sq ft.

In some cases it was more convenient to present the data in milliroentgens per hour per curie (such as the point-source measurements near the filters at the UCLA structure).

In estimating the protection factor of a structure, one assumes that fallout will be evenly distributed on the roof and on the ground outside. Radiation arriving at a detector from contamination on the ground outside was divided into three parts: (1) direct radiation (unscattered), originating on the ground outside and passing through the walls; (2) wall-scattered radiation, originating on the ground outside and scattering in the walls and equipment of the structure; and (3) skyshine radiation, originating on the ground outside and scattering in the air before entering the structure. The majority of the skyshine contribution originates beyond the measurement areas and must be considered in evaluating the protection factor of any structure.

Generally, when the direct and wall-scattering contributions from areas not simulated were estimated, experimental data were used as guide lines. For positions above ground* the material reduction factor for a particular point inside the structure was determined by comparing the experimental results to the calculated dose rate at that point, assuming no structure. This reduction factor was then applied to the calculated dose rate at that point, again assuming no structure, from those areas not simulated. This dose rate from direct radiation was taken from Fig. 4.1 after the rectangular source area was converted to a concentric circular source area (calculations of the dose rate from rectangular source areas are difficult and time consuming). It has been shown[1,2,5] that no serious error is introduced if rectangular source distributions are theoretically converted to circular source distributions for calculation purposes. Figure 4.1 was calculated from the following equation:

$$D = 2\pi SC \int_0^R \frac{\exp\left[-\mu(r^2 + h^2)^{1/2}\right] r\, dr}{r^2 + h^2} \tag{4.3}$$

where S = a source strength per unit area of 1 mc/sq ft

C = dose rate at unit distance from a point source of unit strength, 14.53 mr/hr 1 ft from a 1-mc Co^{60} source

μ = absorption coefficient[6] in air, 2.06×10^{-3} ft^{-1}

h = 3 ft

R and r = radius in feet

Generally, the amount of skyshine radiation contributed to the structure from those areas not simulated was determined by using charts 1, 3, and 5 of Ref. 7 as guide lines. These charts were helpful in determining the solid angle subtended at the detector, the directional distribution, and the attenuation of the radiation. It was assumed, in skyshine-radiation-contribution calculations, that, of the total dose rate 3 ft above an infinite contaminated plane, 20 per cent was contributed by skyshine. This amounts to about 100 mr/hr from a 1 mc/sq ft source distribution of Co^{60}. It was further assumed that all of it originated beyond the measurement area.

Results of specific calculations are presented in more detail in the following sections and in Appendix B.

4.3 UNIVERSITY OF CALIFORNIA AT LOS ANGELES STRUCTURE

A rather detailed study was made of the fallout-radiation protection provided by the basement of the Laboratory of Nuclear Medicine and Radiation Biology on the UCLA campus.

So that the value of D in Eq. 4.1 could be properly ascertained its total value at points in the basement was considered to be made up of several parts:

*See Appendix B for positions below ground.

$$D = R + A + W_m + W_s + W_a + E_m + E_s + E_a \tag{4.4}$$

where R = dose rate from simulated contamination on the roof

A = dose rate from simulated contamination in the areaways

W_m = dose rate from simulated contamination on the ground west of the building

W_s = dose rate from contamination beyond the measurement area west of the building scattered by walls and structure equipment

W_a = dose rate from contamination beyond the measurement area west of the building scattered by the air (skyshine) before entering the structure

E_m = dose rate from simulated contamination on the ground east of the building

E_s = dose rate from wall scattering of radiation originating beyond the measurement area (east)

E_a = dose rate from skyshine, originating beyond the measurement area (east)

In Fig. 2.13 it can be seen that R, A, W_m, and E_m were measured. Since at least 27 in. of concrete was between the basement and the roof, the roof contribution (R) was expected to be very small. However, the 266-curie source was stopped at three locations on the roof, and measurements were made in the basement to estimate the value of R. Its value was estimated to be no greater than 0.01 mr/hr/mc/sq ft in the center of the basement and increasing to about 0.1 mr/hr/mc/sq ft near outside openings. During these measurements the effect of skyshine was vividly illustrated. When the source was stopped in the center of the roof, the dose rate in the basement directly beneath it (through 27 in. of concrete) was about 1 mr/hr. However, at positions No. 81 and No. 82, which were near openings, the dose rate was about 3 mr/hr; and outside in the areaway it was 5 to 10 mr/hr.

The value of A was measured by simulating contamination in the large and small areaways. The contribution from the large areaway was expected to be quite large at most points in the basement. The normalized dose rate at position No. 22 (a sample point for illustration) was 0.38 mr/hr/mc/sq ft.

The tubing was placed 6 ft apart in front of the building out to 72 ft in order to measure the value of W_m. It can be noted from Fig. 1.2 that the ground starts sloping down approximately 50 to 60 ft in front of the building; therefore radiation originating beyond this distance would not reach the basement wall directly. For this reason measurements were not made from distances beyond 72 ft in front of the building. The value of W_m at position No. 22 was found to be 0.13 mr/hr/mc/sq ft.

The measurement area to the rear of the building in the courtyard extended out 60 ft from the building. This area was limited because of operational limitations (see Appendix A). The value of E_m at position No. 22 was found to be 0.096 mr/hr/mc/sq ft.

The values of W_a and W_s were estimated using the Office of Civil and Defense Mobilization (OCDM) Engineering Manual as a guide. A calculation of the solid-angle fraction subtended at the detector by the above-ground portion of the west basement wall, showed that the directional response fraction was 0.085 at position No. 22. This value is the fraction of the skyshine contribution coming through the west basement wall before material attenuation. If the skyshine contribution is assumed to be about 100 mr/hr/mc/sq ft at a distance of 3 ft above an infinite plane, the contribution to position No. 22 would then be 8.5 mr/hr/mc/sq ft before material attenuation. This value would be reduced to about 0.95 mr/hr/mc/sq ft by the 8-in.-thick concrete basement wall. The final contribution (W_a), after a correction for further attenuation in passage through the storage area, is estimated to be no greater than 0.45 mr/hr/mc/sq ft. Skyshine contribution coming through the basement ceiling was found to be negligible.

Since unscattered radiation from beyond the measurement area in front does not impinge upon the basement wall, wall-scattering calculations were limited to scattering from upper floors. The contribution to the basement was found to be negligible, i.e., $W_s < 0.01$ mr/hr/mc/sq ft.

The value of E_a was found in a similar manner to that used to determine W_a and was estimated to be about 0.23 mr/hr/mc/sq ft at position No. 22, assuming that the internal walls, filter systems, pipes, and general equipment presented an equivalent mass of approximately 50 lb/sq ft.

Experimental data were used as comparisons in the estimate of E_s. The ratio of E_m to E_s for a particular detector position was assumed to be equal to the ratio of the dose rate at the basement wall from the measurement area to the dose rate at the basement wall from contamination beyond the measurement area. From Fig. 4.1 this ratio was estimated to be 2.2. Divid ing the value of E_m (0.096 mr/hr/mc/sq ft) by 2.2 gives the value of E_s as 0.044 mr/hr/mc/sq ft at position No. 22.

The value of D in Eq. 4.4 was found for position No. 22 to be 1.34 mr/hr/mc/sq ft by summing all the contributions. The protection factor then was 370. The various contributions to other detector positions were found in a similar manner, and their protection factors were calculated. These protection factors appear in Table 4.1 and are plotted on a basement floor plan in Fig. 4.2.

The location of the areaways strongly affected the value of the protection factors at most points in the basement. In addition, storage areas, air ducts, pipes, and other mechanical equipment affected the values also. For these reasons an approximate protection-factor contour map was prepared (Fig. 4.3).

From the data taken with the source near one of the filters, estimated dose-rate contours were plotted (Fig. 4.4). The data are presented in milliroentgens per hour per curie of radioactive material in or near the filter in the fan room.

4.4 HOME FALLOUT SHELTER

Fallout radiation was simulated on the roof of the house over the fallout shelter. Since the shelter is completely below ground, ground contamination will probably contribute very little compared to roof contamination in the shelter proper. Based on this assumption and on the experimental data taken, the protection factor in the shelter proper is estimated to be at least 10,000.

4.5 LOS ANGELES POLICE DEPARTMENT BUILDING

Because of the complexity of the structure and obvious operational limitations, only two exposures were made at this structure. The results were used as guide lines in estimating the protection factors in the communications section.

Because of the massiveness of the structure, radiation reaching the points of interest was assumed to originate (1) from the low roof above the teletype room and other locations, (2) from the upstairs parking lot, and (3) from the ground east of the structure.

Roof contribution was determined by taking data from the roof exposure and by applying these data and the symmetry of the area to areas on the roof not measured.

Skyshine contribution from the upstairs parking lot was estimated by using the OCDM Engineering Manual.[7] Wall-scattered and direct contributions were estimated by using Fig. 4.1 and experimental data for comparison. Ground contribution from the east side was estimated by using the OCDM Engineering Manual.[7]

The results indicate the protection factor in the teletype room to be about 50 and those near the radio and telephone operators to be about 150. The results are presented in Fig. 4.5 in the form of an approximate contour map.

It must be emphasized that these are only rough approximations. A more detailed analysis may result in a refinement of accuracy. However, it is believed that these numbers represent reasonable minimum values of the protection factors.

4.6 TYPICAL CLASSROOM AT NORTH HOLLYWOOD HIGH SCHOOL

Measurements were made on the first floor of this structure from simulated contamination on the roof and on two small areas on the ground to the north and east of the building. Skyshine contribution through the windows and openings was estimated by using the OCDM Manual[7]

as a guide. Direct and wall-scattered contributions from beyond the measurement areas were estimated by the use of Fig. 4.1 and experimental data for comparisons. The contribution from the west side was estimated by the use of symmetry and the data taken from the east side.

The presence of nearby buildings was not considered in estimating the contribution from beyond the measurement areas. Fallout on the roof of a nearby structure would tend to increase the estimations, but this would be somewhat compensated by the structure's attenuation of the radiation originating on the other side of the building.

The protection factors were found to be quite low, predominantly because of the presence of numerous windows and openings and light-partition construction. Protection factors below the window level are presented in Fig. 4.6 in the form of an estimated contour map.

4.7 DISCUSSION AND GENERAL CONCLUSIONS

Fully accurate predetermination of a protection factor cannot be achieved because of the many unpredictable effects associated with a fallout situation. These unpredictable effects include areas of nonuniform contamination and accumulations on walls and window ledges. Since the results presented in this report assume a uniform fallout field with no accumulation on window ledges or walls, they represent approximations of the protection factors.

Analysis of the data for the UCLA structure and analytical computations show that most of the radiation arriving at points in the center hallway of the basement originated as skyshine radiation. This fact indicates that in a structure of this type it is very important to consider skyshine radiation as a separate component. Placing the source on the roof and noting the dose-rate reading near outside openings vividly illustrated the significance of such a consideration.

Since the intervening floors from basement to ceiling each contained approximately 9 in. of concrete, radiation arriving in the basement would essentially come through the basement wall (above ground level) or from the areaways. An extra concrete wall, sandbags, or earth placed against the outside basement wall from ground level to basement-ceiling level would result in greatly increased protection in the center of the basement.

Accumulation of radioactive material in the filter system may present a problem if the circulation system is turned on while the fallout is descending.

The analysis of the UCLA structure was rather detailed, both experimentally and analytically. However, a more thorough analysis may result in different values for protection factors. The author feels that the results represent a reasonable minimum of the protection factors at most points in the basement. This assumes no fallout on areas such as walls, ledges, or window sills.

The protection factor in the family fallout shelter was estimated to be quite high, predominantly because (1) the shelter was completely below ground, (2) its roof consisted of approximately 24 in. of concrete, and (3) the design of the entranceway was good.

The protection factor in the center of the communications section of the Los Angeles Police building was estimated to be between 100 and 200. Most of the contribution was from skyshine radiation originating on the upstairs parking lot and beyond. The communications section is about 80 ft from the parking lot, resulting in a rather small solid-angle fraction subtended by the windows. There are several intervening glass and plasterboard walls as well as desks, concrete posts, etc. These were assumed to present a mass of about 25 lb/sq ft.

If there were several cars in the parking lot during a fallout situation, radiation originating on top of the cars would penetrate more directly into the communications section, thereby lowering the protection factors.

The protection factors would be substantially increased if a concrete wall were constructed between the upstairs parking lot and the communications section. Protection in the teletype room could be improved if the roof thickness were increased or if the outside east wall were widened.

The 12-in.-thick concrete wall below the windows at the upstairs parking lot raised the protection factor. Without this concrete barrier, it would have been much lower, perhaps by as much as a factor of 4.

Protection factors in the classroom structure were rather low because of the presence of numerous windows and openings and because of the relatively light construction of inside partitions.

This structure was typical of Los Angeles classroom buildings built several years ago. Its framework was heavy and substantial, indicating that the inside partitions may have consisted of concrete. However, an inspection of the blueprints showed that these partitions were composed of light materials, a fact that emphasizes the importance of a detailed analysis of blueprints in estimating fallout protection.

Valuable data were obtained from all the tests at the four structures. The objectives were met; and, in general, the project was successful. There were no unusual incidents, and the measurements were made within the criteria established for radiation-safety operations.

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1. J. A. Auxier et al., *Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources*, Report CEX-58.1, January 1959.
2. C. E. Eisenhauer, *Analysis of Experiments on Light Residential Structures with Distributed Co^{60} Sources*, Report NBS-6539, National Bureau of Standards, October 1959.
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Other references pertaining to the subject but not cited in text:

8. J. R. Cunningham et al., *Protection Factors for Houses Using Radioactive Sources*, Defense Research Chemical Laboratories, Ottawa, DRCL-260, November 1957.
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11. B. J. Stralser et al., *Experimental Evaluation of Systems for Determining the Radiation Protection Afforded by Residential Structures*, Report CEX-58.6, to be published.
12. Z. Burson, D. Parry, and H. Borella, *Experimental Evaluation of the Fallout-radiation Protection Afforded by a Southwestern Residence*, Report CEX-60.5, February 1962.
13. Z. Burson and H. Borella, *Experimental Evaluation of the Radiation Protection Provided by an Earth-covered Shelter*, Report CEX-60.6, February 1962.

TABLE 4:1—PROTECTION FACTORS AT POSITIONS IN THE BASEMENT OF THE LABORATORY OF NUCLEAR MEDICINE AND RADIATION BIOLOGY AT UCLA

Position	P.F.	Position	P.F.	Position	P.F.	Position	P.F.
1	2800	23	400	45	520	67	1500
2	3000	24	410	46	460	68	340
3	2300	25	450	47	450	69	56
4	2000	26	900	48	320	70	360
5	520	27	180	49	410	71	100
6	1400	28	39	50	250	72	16
7	640	29	39	51	310	73	18
8	620	30	97	52	470	74	78
9	260	31	170	53	700	75	350
10	420	32	160	54	340	76	380
11	390	33	54	55	480	77	180
12	510	34	450	56	530	78	500
13	540	35	550	57	330	79	2400
14	210	36	600	58	330	80	92
15	140	37	1400	59	350	81	38
16	70	38	1600	60	350	82	12
17	110	39	1400	61	310	83	360
18	160	40	380	62	320	84	74
19	300	41	380	63	390	85	430
20	34	42	610	64	430	86	910
21	380	43	740	65	490		
22	370	44	370	66	1400		

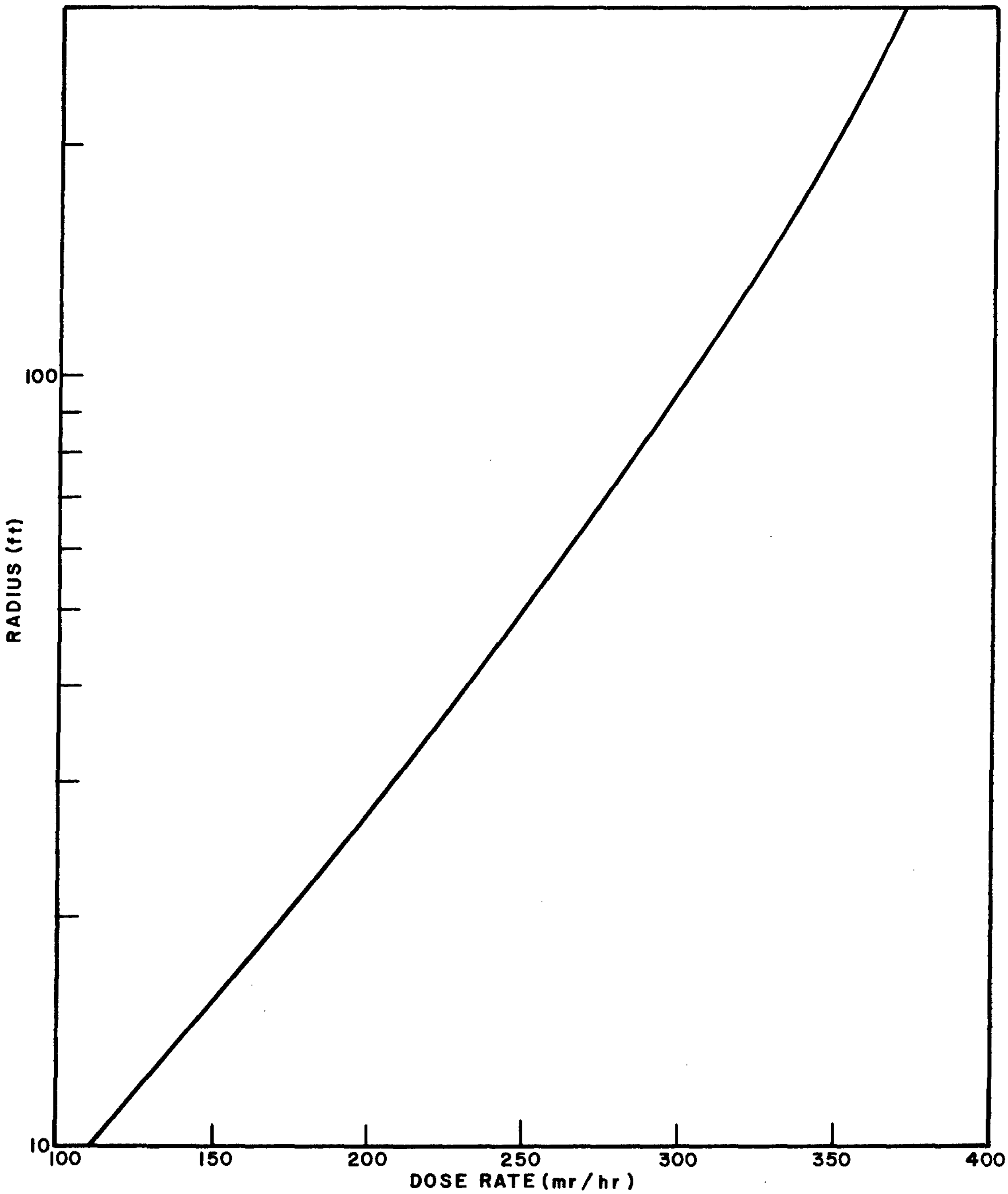

Fig. 4.1—Exposure dose rate as a function of radius of a circular area contaminated with Co^{60} to a source density of 1 mc/sq ft. Skyshine not considered.

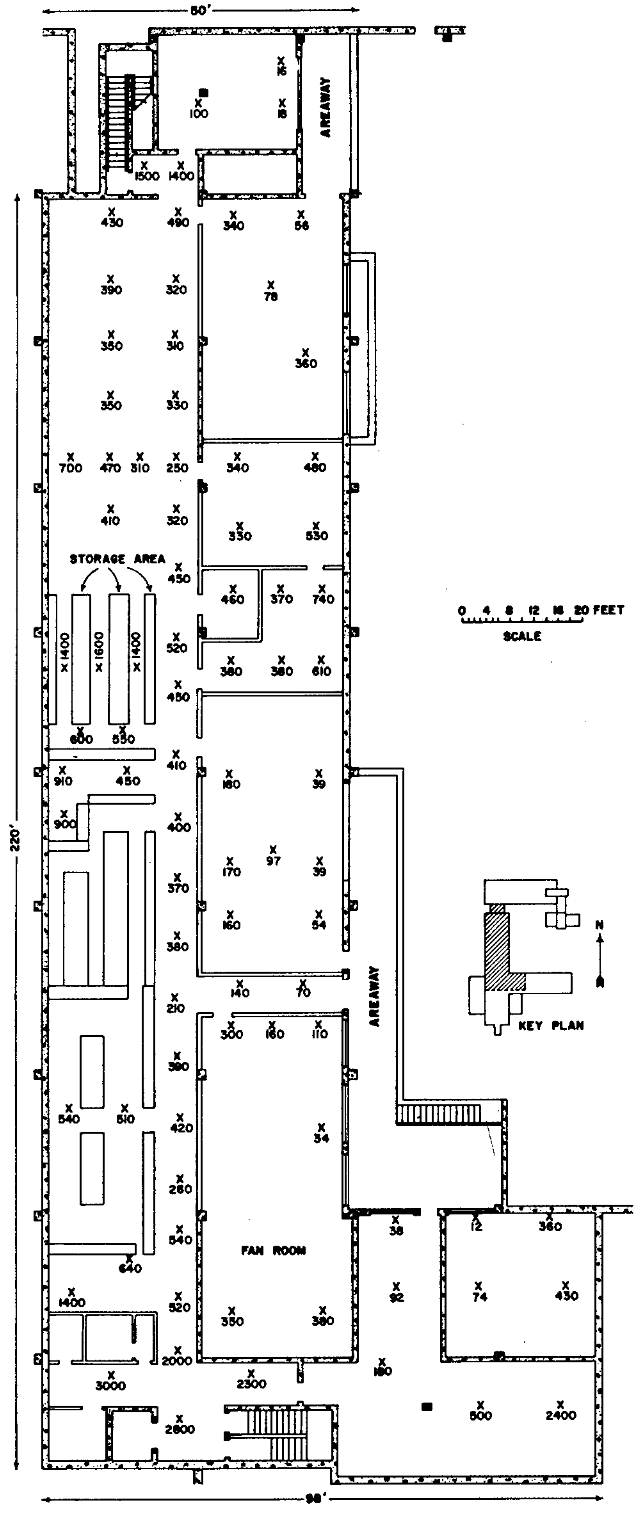

Fig. 4.2—Protection factors plotted on basement floor plan of UCLA structure.

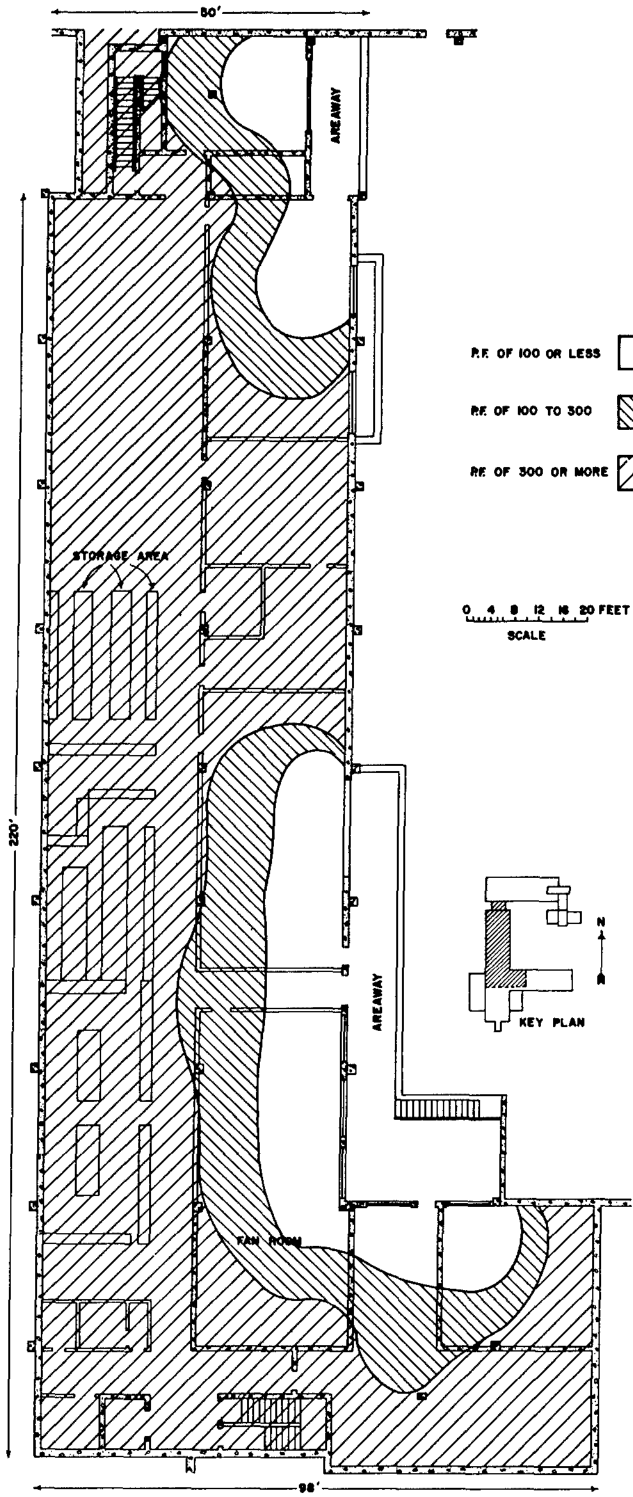

Fig. 4.3—Approximate protection factor contour map of basement of UCLA structure.

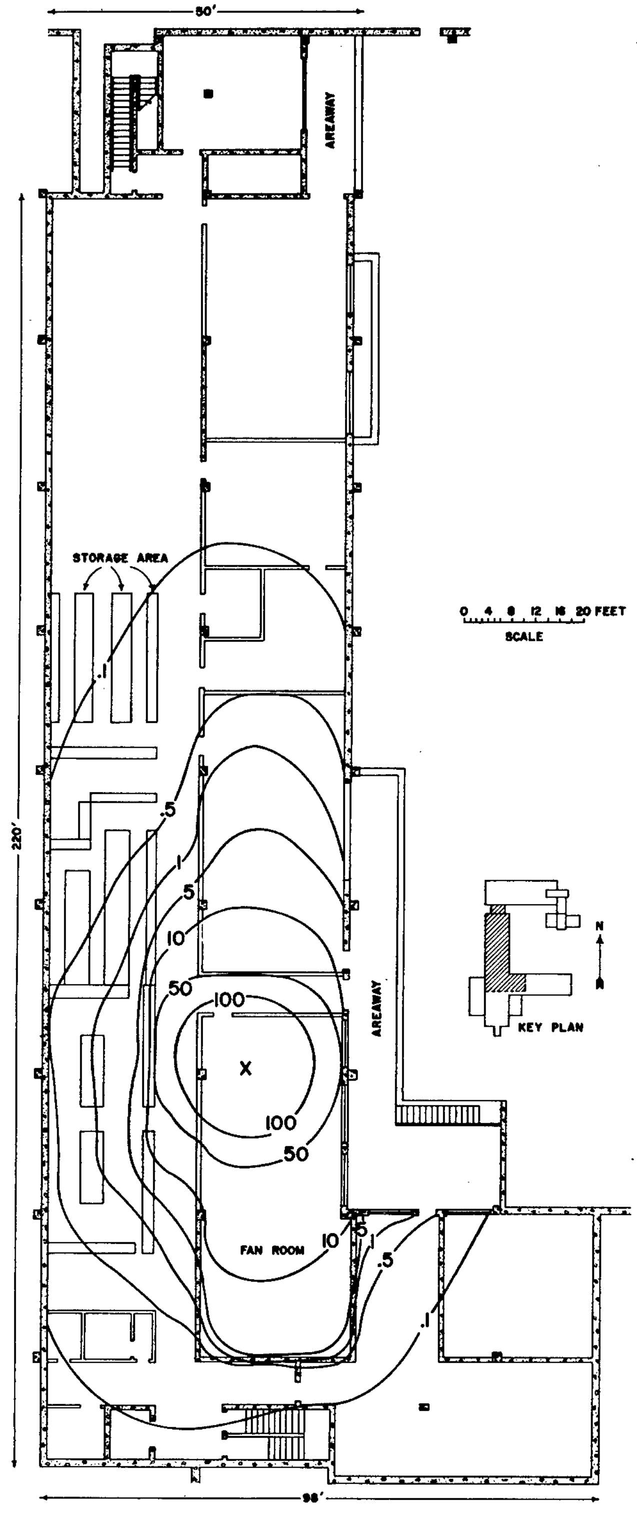

Fig. 4.4—Estimated normalized (mr/hr/curie) dose-rate contours from a point source placed near filter of UCLA structure.

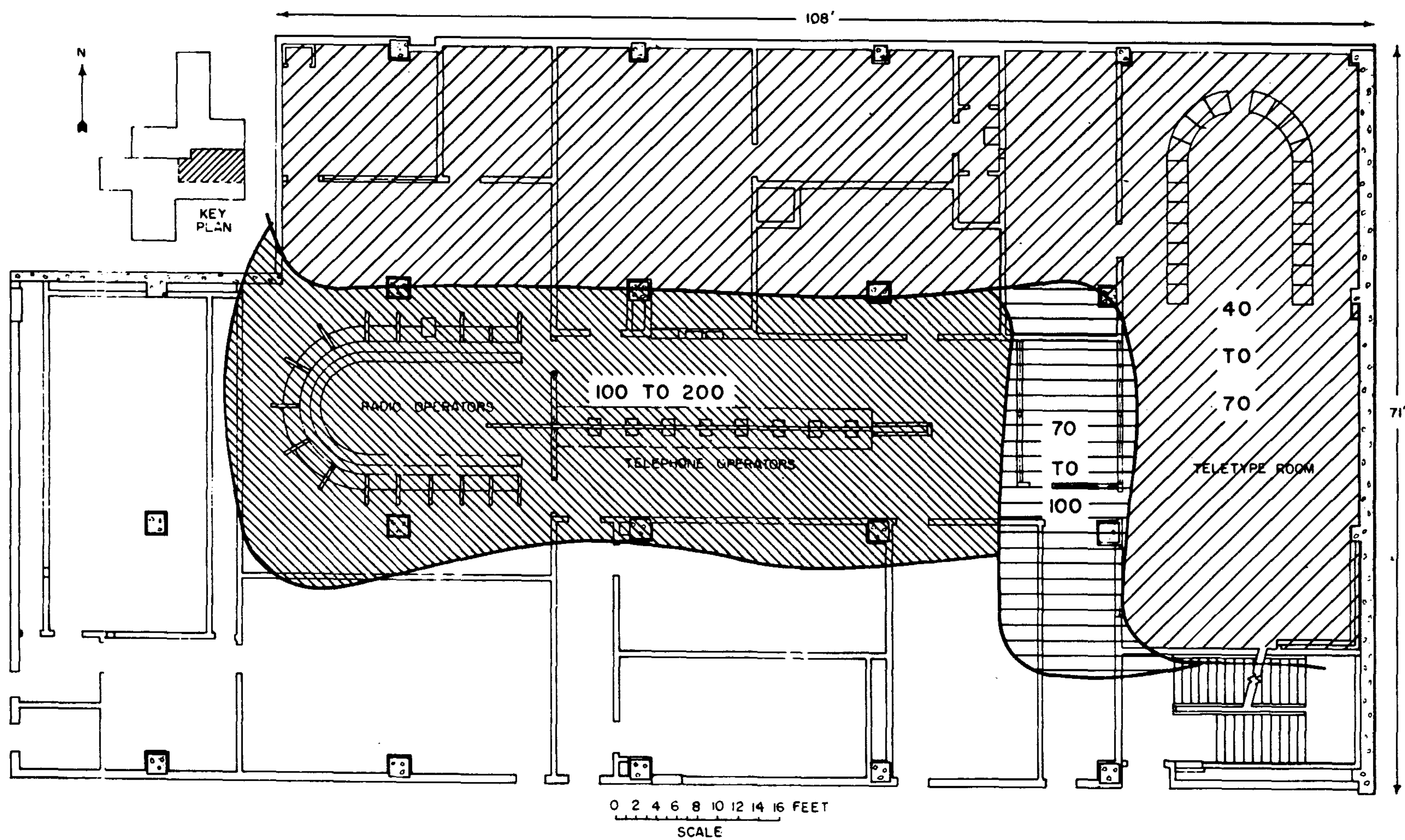

Fig. 4.5—Estimated protection factor contour map of communications section of Los Angeles Police Department building.

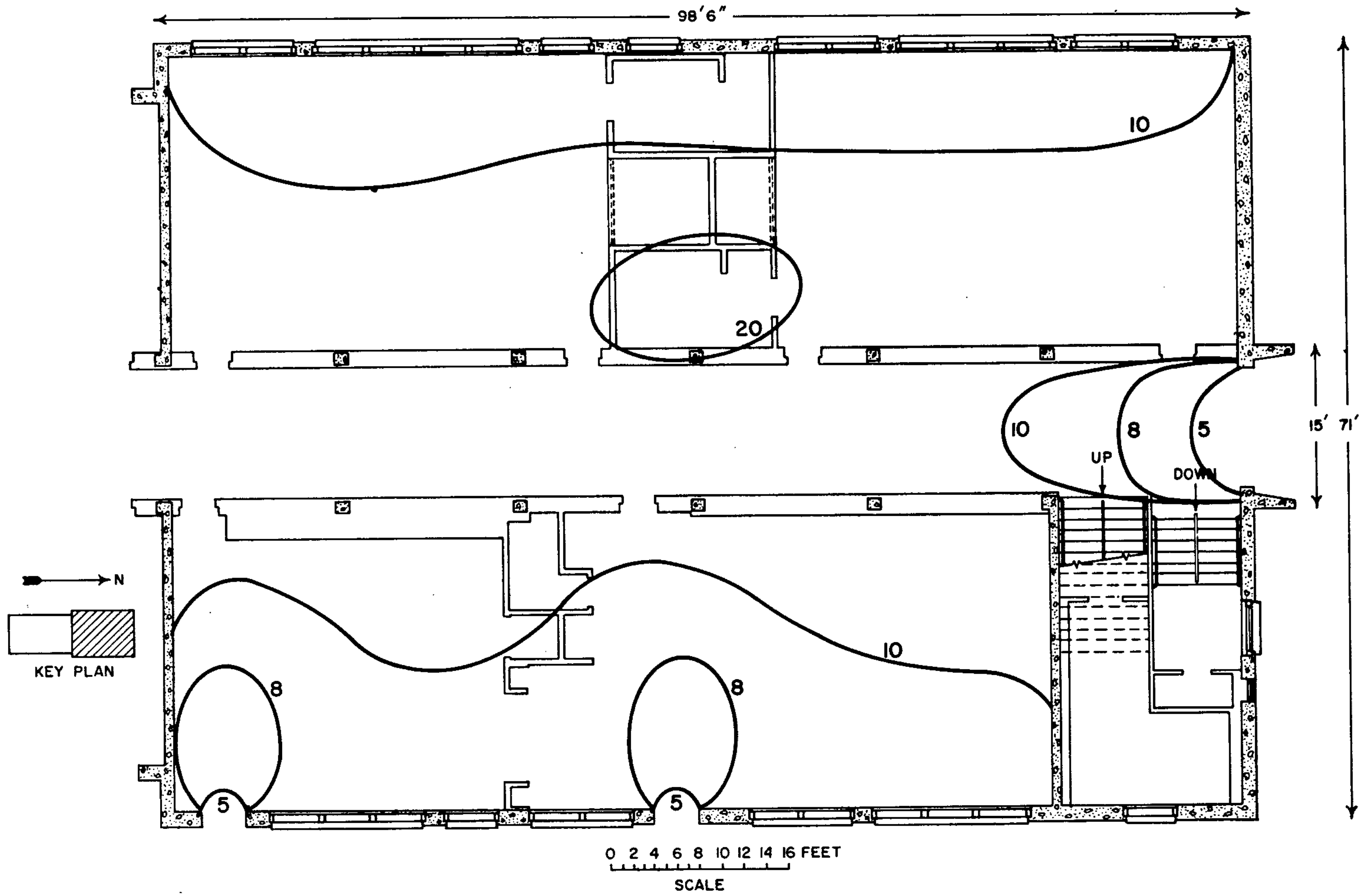

Fig. 4.6—Estimated protection factor contour map of first floor of North Hollywood High School classroom structure.

Appendix A

RADIOLOGICAL SAFETY OPERATIONS

This appendix describes the radiation-safety techniques used during the project. The tests were performed at night or on weekends with minimum inconvenience and disruption in the normal activities of the organizations and personnel concerned. No unusual incidents occurred, and the measurements were safely completed within the radiological-safety criteria established.

Radiation-safety responsibility was shared by Edgerton, Germeshausen & Grier, Inc. (EG&G), the contracting agency performing the tests, and the supporting organizations. In general, EG&G was responsible for handling the sources, conducting the measurements, and for the safety of the people directly associated with the tests. Supporting organizations were responsible for the radiation safety of personnel not associated with the tests. These organizations are listed below:

Structure	Organizations
UCLA	Health Physics Section of Laboratory of Nuclear Medicine and Radiation Biology at UCLA
Fallout shelter	EG&G and Los Angeles Civil Defense
Los Angeles Police Department building	Los Angeles City Health and Police Departments
North Hollywood High School classroom	Los Angeles City Health Department and Civil Defense

Although the tests were conducted in the evenings and on weekends, some people were present in the buildings or on the grounds who were not involved in making the survey. The use of radioactive sources made it necessary to establish areas in and around the structures as radiation zones and to limit access to these areas.

The basic radiological-safety program was one of strict personnel control. Before each exposure officials from EG&G and supporting organizations decided which areas of the buildings and grounds would be restricted as radiation zones during the exposure. In general, restrictions were such that any uncontrolled areas would not receive a dose of more than 2 mr in any 1-hr period. Barricades and signs were then placed at appropriate locations. Designated personnel were stationed at strategic positions to visually observe these areas and to restrict access. Film badges and pocket chambers were issued to all supporting personnel. Before the source was released, a final visual inspection was made to ensure that no unauthorized persons were present in the restricted areas. After these precautionary checks were made, the exposure was started.

During the exposure health physics personnel made surveys of the perimeter of the designated zone to ensure that the radiation levels did not exceed the established criteria. Entrance into the controlled area was restricted during the exposure; personnel were allowed only if accompanied by a designated health physics surveyor. Radio contact was maintained between the EG&G control center and supporting personnel by two-way radio.

Film badges and pocket chambers were used to monitor total doses received by unrestricted areas as well as by all operational and supporting organizations.*

There were existing residential areas approximately 300 ft to the rear of the UCLA structure. Criteria established for the exposures at this building were such that the residential areas would not receive more than a total dose of 60 mr for the entire seven-day project. Film badges and pocket chambers located on a fence 225 ft to the rear of the building recorded a total dose of 50 mr. The residential areas therefore received less than 50 mr total dose.

Criteria established for measurements at other structures were that unrestricted areas would not receive more than 2 mr in any 1-hr period. Film badges and pocket chambers indicated doses were well within this limit.

Operational personnel received a total dose of less than 100 mr for the entire operation. Supporting personnel from the Los Angeles Office of Civil Defense and the Los Angeles City Health and Police Departments received a total dose of less than 10 mr as read by pocket chambers. All measurements were conducted safely within the radiological criteria established.

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*EG&G furnished all film badges and pocket chambers except for those carried by personnel from the UCLA Health Physics Section.

Appendix B

SAMPLES OF DATA, ANALYSIS, AND EVALUATION

This appendix contains samples of data and the process used to calculate protection factors. Reference is made to Chap. 4 for definitions and explanations of all terms used.

Table B.1 shows a sample of data and the process for correction and normalization. This sample is from measurements made with the tubing placed in the large areaway at the UCLA structure. Table 3.1 contains the necessary information for correction and normalization.

Table B.2 contains the measured and estimated values (normalized) of the contribution from different portions of the building to a particular detector position. The sum of these contributions was used to calculate the protection factor at that position.

The values of A, W_m, and E_m were measured directly. The value of R was estimated from the data taken when the source was on the roof. Its value was estimated to be no greater than 0.01 mr/hr/mc/sq ft in the center of the basement and increasing to possibly 0.1 mr/hr/mc/sq ft near outside openings.

The value of W_s was estimated from the OCDM Manual.[1] However, it is noted that the ground level slopes downward from the building. Any radiation originating on the ground beyond the measurement area in front of the building will not reach the basement wall directly. Therefore wall scattering from the front direction was considered to exist only on upper floors. Attenuation through the 9-in. first floor resulted in a negligible contribution (<0.01 mr/hr/mc/sq ft).

The value of W_a was also estimated from OCDM Manual. Solid-angle fractions and directional-response values were found for the basement wall portion above ground. The position of the storage areas in relation to the detector locations was roughly considered in estimating the values of W_a. The dose rate contributed by skyshine radiation was assumed to be 100 mr/hr at 3 ft above a contaminated field of 1 mc/sq ft of Co^{60}. Skyshine contribution through the basement ceiling was found to be negligible compared to the contribution through the basement wall.

The value of E_a was determined in a manner similar to W_a with rough consideration of the shielding provided by the internal walls, air ducts, pipes, etc.

Experimental data were used as guide lines in estimating the values of E_s. Essentially, radiation originating on the ground outside did not reach the detectors directly. The geometry relation for E_m and E_s were assumed to be the same for wall-scattered radiation. (Wall scattering in upper floors was negligible.) Therefore the ratio of E_m to E_s for a particular detector position was assumed to be equal to the ratio of the dose rate at the basement wall from the measurement area to the dose rate at the basement wall from contamination beyond the measurement area. This ratio was estimated to be 2.2 by the use of Fig. 4.1.

REFERENCE

1. *OCDM Engineering Manual;* Design and Review of Structures for Protection from Fallout Gamma Radiation, Part A (revised preliminary edition), Office of Civil and Defense Mobilization, December 1960.

TABLE B.1—CORRECTION AND NORMALIZATION OF DATA (UCLA STRUCTURE)

Position	Average reading from large areaway, mr	Corrected for background, temperature, and pressure, mr	Corrected for calibration, mr	Normalized, mr/hr/mc/sq ft
8	1.1	1.1	1.3	0.14
10	2.4	2.4	2.9	0.30
12	1.9	1.9	2.3	0.24
14	7.0	7.0	8.3	0.90
16	40	40	48	5.1
18	13	13	15	1.7
20	82	82	98	10.5
22	3.0	3.0	3.6	0.38
24	1.3	1.3	1.5	0.17
26	0.3	0.3	0.4	0.04
28	72	72	86	9.2
30	11	11	13	1.4

TABLE B.2—ESTIMATED DOSE RATE* CONTRIBUTIONS AT A PARTICULAR DETECTOR POSITION (UCLA STRUCTURE)†

Position	R	A	W_m	W_s	W_a	E_m	E_s	E_a	Sum D	P.F.
8	<0.01	0.14	0.083	<0.01	0.45	0.005	0.002	0.11	0.80	620
10	<0.01	0.30	0.15	<0.01	0.45	0.034	0.015	0.23	1.2	420
12	<0.01	0.24	0.16	<0.01	0.30	0.048	0.022	0.20	0.99	510
14	<0.01	0.90	0.17	<0.01	0.45	0.067	0.030	0.70	2.3	210
16	0.01	5.1	0.11	<0.01	0.20	0.14	0.063	1.5	7.2	70
18	0.01	1.7	0.12	<0.01	0.20	0.21	0.10	0.80	3.1	160
20	0.05	10.5	0.034	<0.01	0.17	0.24	0.11	3.0	14	34
22	<0.01	0.38	0.13	<0.01	0.45	0.096	0.044	0.23	1.3	370
24	<0.01	0.17	0.19	<0.01	0.45	0.12	0.054	0.23	1.2	410
26	<0.01	0.04	0.16	<0.01	0.20	0.024	0.011	0.10	0.55	900
28	0.05	9.2	0.083	<0.01	0.17	0.096	0.044	3.0	13	39
30	0.01	1.4	0.14	<0.01	0.23	0.25	0.11	2.0	5.2	97

*Dose rate normalized to mr/hr/mc/sq ft.

†See Eq. 4.4 of Sec. 4.3 for definition of terms.

Appendix C

DETECTOR POSITION DESCRIPTIONS

The position of a radiation detector in relation to its immediate surroundings undoubtedly affects the radiation dosage it receives. For this reason a brief description of each of the detector positions at the UCLA structure is presented in Table C.1. The detectors were located in the most open areas possible so that scattered radiation from nearby equipment would be reduced to a minimum. However, some positions were by necessity near storage areas, walls, etc., which may have affected the measured dose. Figures 1.5, 2.18, and 2.19 are typical scenes in the UCLA structure showing such locations.

TABLE C.1—DETECTOR POSITIONS IN UCLA STRUCTURE

Position	Description
1	Clear, in line with hallway
2, 3	Clear, centered
4, 5	Clear (positions in hallway were 10 ft apart and 3 ft from wall)
6	4 ft from walls, near water bottles
7	Near storage area
8–11	Clear
12	6 in. from boxes
13	3 ft from filing cabinets
14–18	Clear
19	About 4 ft from walls
20	3 ft from maze of air ducts, filters, etc.
21–24	Clear
25	4 ft from storage areas
26	3 ft from wall and 3 ft from storage area
27	Clear
28	1 ft to storage racks
29	Clear
30	2 ft to boxes
31	Clear
32	Near small pipes
33, 34	Clear
35, 36	Center of storage areas, 3 ft to storage
37–39	Center of storage areas, $1\frac{1}{2}$ ft to storage
40–44	Reasonably clear in office
45	Clear
46	In small room, near electronic equipment
47, 48	Clear
49	1 ft from pipes, etc., general storage
50	Clear
51, 52	4 ft to storage
53	3 ft to wall
54–57	Clear in machine shop
58–62	Clear
63	6 in. to wooden cabinet
64	1 ft to wooden cabinet
65–67	Clear
68	3 ft below air duct, near small machine
69	3 ft below air duct
70	near pipes and ducts
71	6 in. to post
72, 73	Clear
74–76	2 ft below air duct
77	About 4 ft from pipes
78, 79	Clear
80	About 3 ft to engine
81	Clear
82, 83	About $1\frac{1}{2}$ ft to wall
84	3 ft to large generator
86	3 ft to wall
101–230	Reasonably clear, in offices, laboratories, and hallways

Appendix D

THEORETICAL PREDICTION OF PROTECTION FACTOR

By P. H. Huff

Holmes & Narver, Inc.

D.1 INTRODUCTION

This part of the project was undertaken to predict a protection factor for the new UCLA Laboratory of Nuclear Medicine and Radiation Biology. Since current fallout-shelter surveys have a theoretical basis, it was felt that the work at this building offered an opportunity to compare the experimental results, as described in the body of this report, with the theoretical predictions of this appendix.

D.2 PROCEDURE

D.2.1 Description of Building

The laboratory is a two-story building, built in the shape of a rough letter "U" (see Fig. 1.2). The first and second floors and the roof slabs are 9-in.-thick reinforced concrete, supported at 24-ft centers by reinforced-concrete columns. The central part of the U has a full basement, but the wings have no basement. The floor and roof slabs extend about 4 ft beyond the exterior column lines. The windows are in the plane of the exterior column lines, and a full-story-high vertical masonry screen is located at the slab cantilever extremities. The slabs were prestressed and erected by a lift-slab procedure.

West of the building, finished grade is reasonably flat for a distance of some 50 or 60 ft. The grade then slopes down at about one vertical to ten horizontal for approximately another 100 ft. The grade was reasonably flat on other sides of the building where source tubing was placed.

D.2.2 Location of Detector Position of Interest

Several factors were considered in determining the location of the detector position for which the protection factor should be calculated. Among them were the following:

1. The point should coincide with an EG&G dosimeter location.
2. The point should not be adjacent to a column or other shielding discontinuity.
3. The point should be in the basement, a location of primary interest in fallout sheltering.
4. The point should be close enough to the exterior basement-level areaway to require consideration of the contribution from the areaway to the dose at the point.
5. The point should be unsymmetrically located to generalize the method of calculation.

With these considerations in mind, position No. 22 (see Fig. 3.1) was chosen for computation.

D.2.3 Assumptions

The method used for the protection-factor calculations is that described in the OCDM publication, *Fallout Shelter Surveys: Guide for Architects and Engineers*. The methods of the OCDM Guide can be applied if the structure is idealized and if some simplifying assumptions are made.

Idealized plans for the two separate calculations required are shown in Appendix E. The assumptions are described as they occur in the calculations. Among the more important are the following:

1. The building is assumed to be a rectangular two-story structure with basement (see Figs. E.1 to E.3 in Appendix E).
2. Fallout is assumed to cover the roof of this building, the ground along the two long sides, and the basement-level areaway.
3. The basement-level areaway is assumed to be rectangular in plan, 72 ft long by 10 ft wide.
4. The detector at position No. 22 is 10.75 ft below the first floor. The curves in the OCDM Guide, however, are drawn for a detector only 5 ft below the first floor. This difference is compensated for by adjusting the contribution in the ratio of the solid angles subtended at the detector by the intersection of the ground level and the basement wall.

D.3 RESULTS

The calculations are included as Appendix E. A fallout protection factor of 80 was computed for position No. 22. However, a slightly different method of handling the detector height in the basement resulted in a protection factor of roughly 115.

D.4 DISCUSSION

Some of the factors affecting the predicted protection factor, and hence possibly contributing to the discrepancy between the measured and predicted factors are:

1. Idealization. Any large, complex structure must be simplified prior to making a rapid analysis. This probably results in some loss of accuracy, but the amount and direction of this loss is difficult to estimate.
2. Detector-height variation. As previously observed (see Sec. D.3), this is a sensitive parameter.
3. Contribution from small, finite areas. The OCDM Guide prescribes no method for analysis of the dose contribution from small, finite areas such as the basement areaway at the UCLA building. Obviously, the computed contribution from such areas is affected by the computer's approach to the problem.
4. Supplementary shielding. Generally, the computed shielding results only from the protection of the structure itself. In many cases, however, supplementary shielding is provided by furniture, equipment, storage racks, etc. The effect of this shielding can, in general, be estimated only roughly.

In the UCLA structure an air-conditioning unit located in the basement adjacent to the areaway probably shielded the detector a small amount. The unit was roughly rectangular, about 2 ft high by 6 ft square, and was suspended just below the first-floor slab. In addition, a group of sheet-metal racks containing soil samples was located in the northwest area of the basement.

D.5 CONCLUSION

It is felt that the computed protection factor of 80 for detector position No. 22 in this building probably represents a lower limit, with the upper limit estimated to be about 140.

Appendix E

PROTECTION FACTOR CALCULATIONS FOR THE LABORATORY OF NUCLEAR MEDICINE AND RADIATION BIOLOGY AT THE UNIVERSITY OF CALIFORNIA AT LOS ANGELES

By P. H. Huff

Holmes & Narver, Inc.

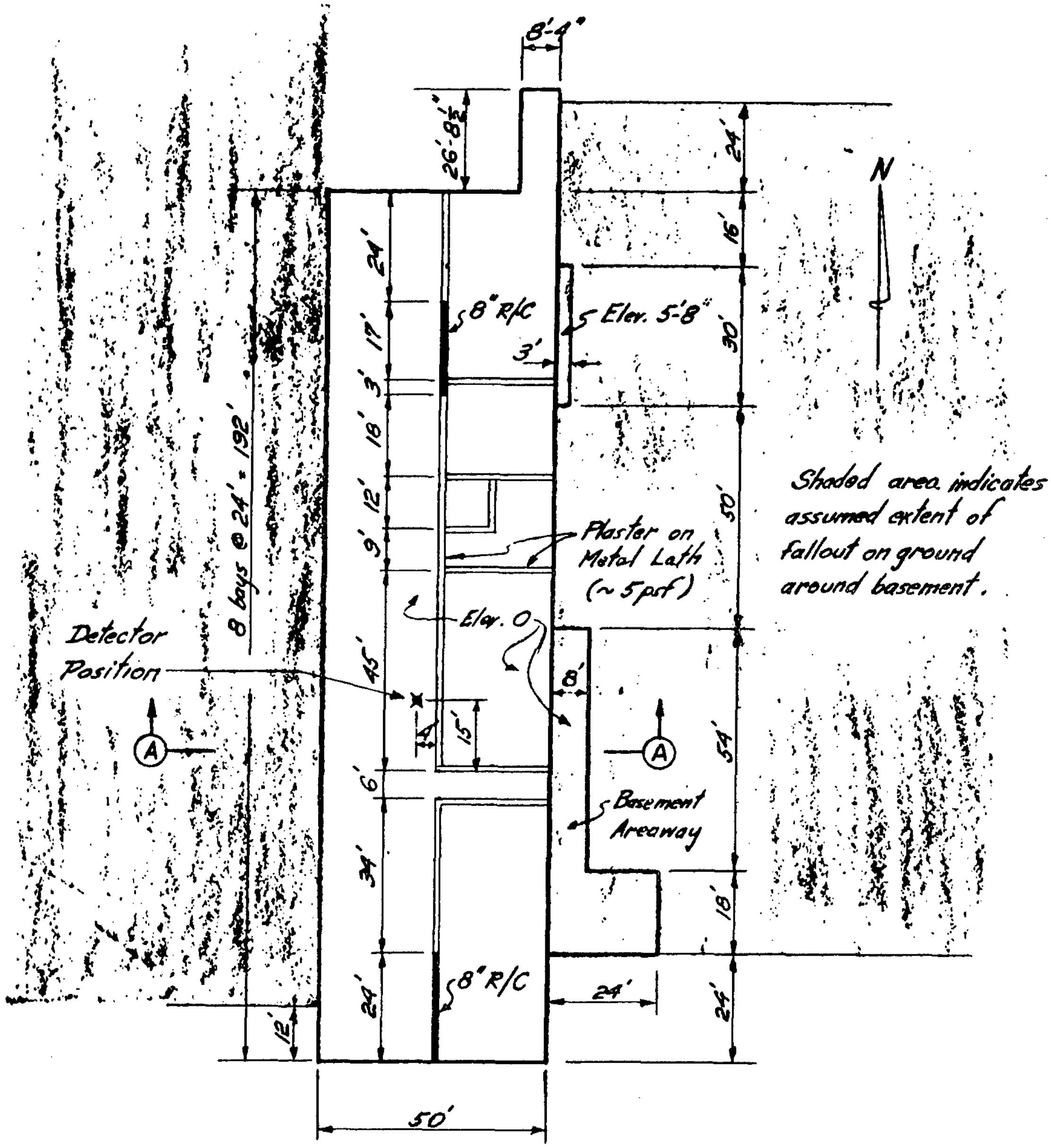


Figure E-1

UCLA Laboratory, Basement Plan

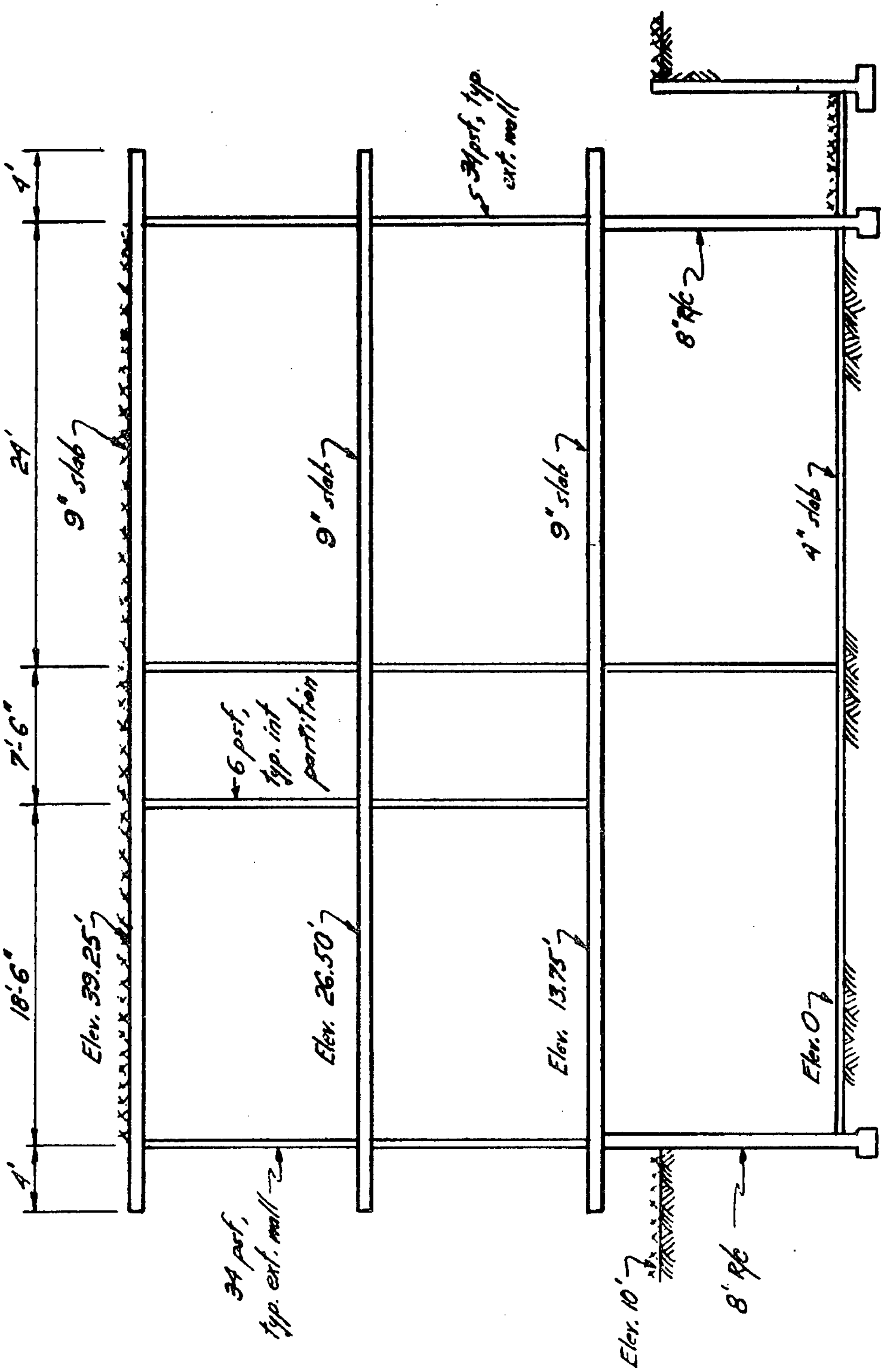


Figure E-2

Section A-A

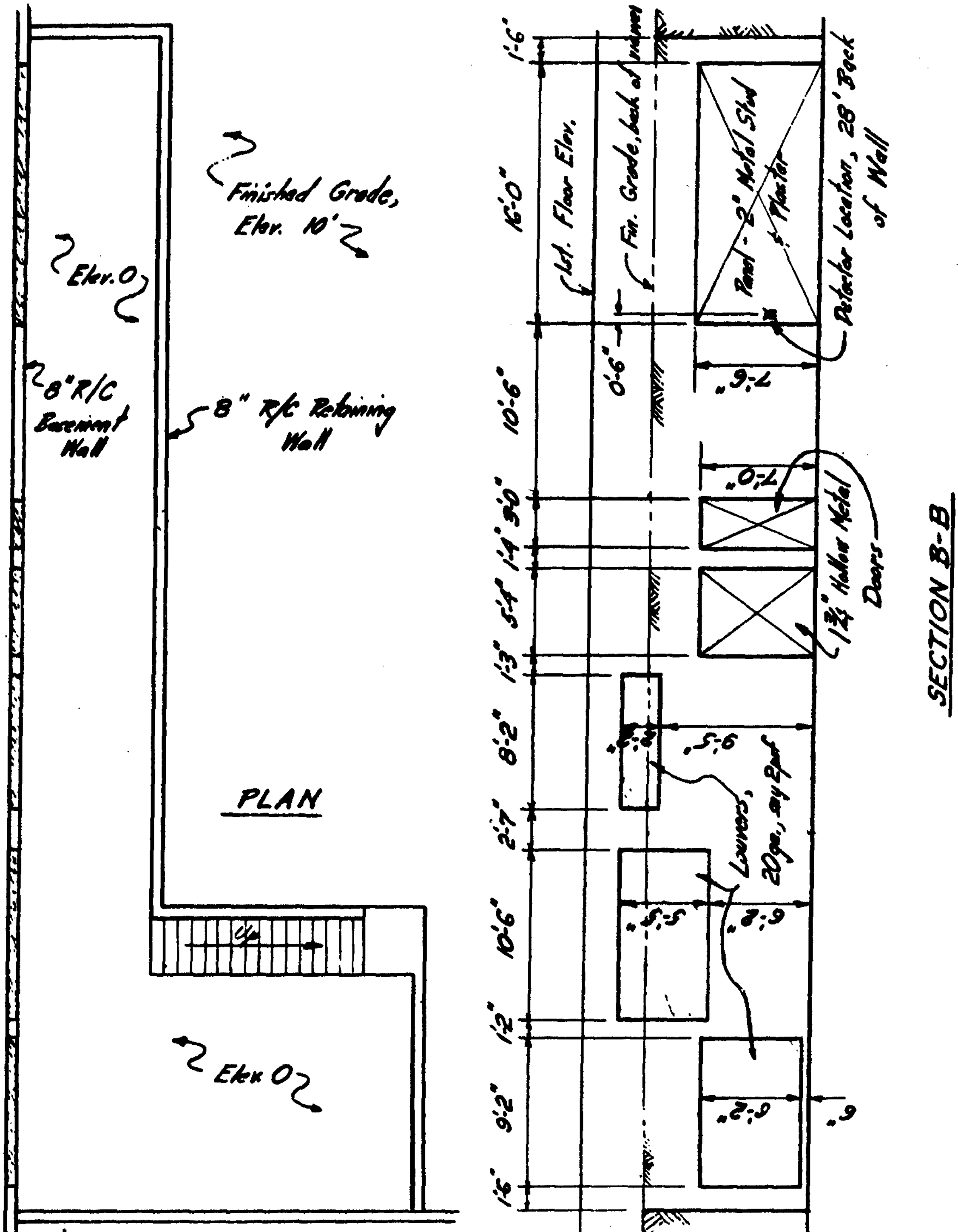


Figure E-3 Basement Areaway

Ref.: "Fallout Shelter Surveys: Guide for Architects and Engineers" OCDM

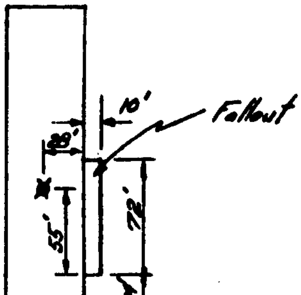
Roof Contribution

27" concrete barrier & 36.25 ft. from roof to detector - there is **no roof contribution**

Ground Contribution

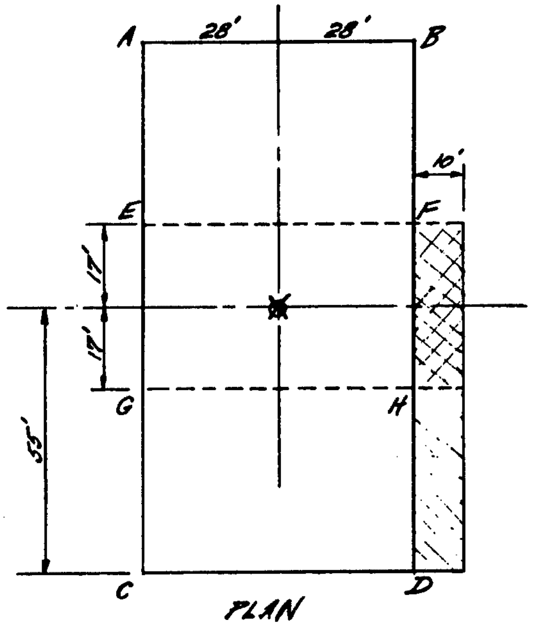
The ground contribution will be considered to be the sum of two reduction factors - (1) Contribution from the basement-level areaway, and (2) Contribution from sources on finished grade. The 3'x30' areaway is neglected because it is completely covered by 1st Floor slab overhang. The areaway at the north end of the basement is not considered because of its remoteness to the detector; and also because of its small area.

A. Basement-Level Areaway



Idealized Plan

Since detector is 3' above the plane of the fallout outside, computation will proceed as for an "above-ground structure".



Contribution from Shaded Area, Procedure

1. Compute EFGH, assuming it to be surrounded by infinite fallout field. Consider apertures at louvers.
2. Use perimeter wall ratio to find contribution from wall FH.
3. Repeat Step ① for building ABCD.
4. Repeat Step ② for contribution from wall BD
5. Subtract ② from ④
6. Shaded area contribution = 0.04 [② + ½⑤]

0.04 corrects for a 10' wide strip rather than infinite plane contamination. See Chart 6 - to find contribution from a 10' wide strip 28' to 38' from detector, use 110' aperture width, then take 0.8 to correct for the horizontal angle. Use of Table CF-3 gives same answer. "

1. Area = 34 × 56 = 1904, say 1900 sq. ft.

X_w = 100(8" conc.) + 5(Plaster Partition) = 105 psf

% Apertures (see Sh. 3) = $\frac{16+3+1.7}{34} = \frac{20.7}{34} = 0.61 = 61\%$

Detector is above all sills, so all corrections are by factor of 1 (See Table CF-1)

For 100% solid wall, contribution = 0.05 (Chart 3)

For "apertures", say 3 psf, " = 0.50

Adjusted contribution = $\underset{0.305}{0.61(0.5)} + \underset{0.0195}{0.39(0.05)} = 0.32$

2. Short Wall Only –

$\frac{34}{2 \times 34 + 2 \times 56} = \frac{34}{180} = 0.189$

Adjusted contribution, side FH only = 0.189(0.32) = 0.06

3. Area = 56 × 110 = 6160 sq. ft.

X_w = 105 psf

% apertures = $\frac{16+3+5.3+9.17}{72} = \frac{33.47}{72} = 0.465 = 46.5\%$

for detector above sill

% apertures = $\frac{8.17+10.5}{72} = \frac{18.67}{72} = 0.26 = 26\%$

for detector below sill

For 100% solid wall, contribution = 0.031

For Apertures, say 3 psf, " = 0.37

Adjusted contribution = 0.465(0.37)(1) + 0.26(0.37)(0.2) + (1.00 − 0.465 − 0.26)(0.03) =

= 0.172 + 0.019 + 0.008 = 0.199

4. Long Wall Only –

$$\frac{110}{2 \times 110 + 2 \times 56} = \frac{110}{332} = 0.332$$

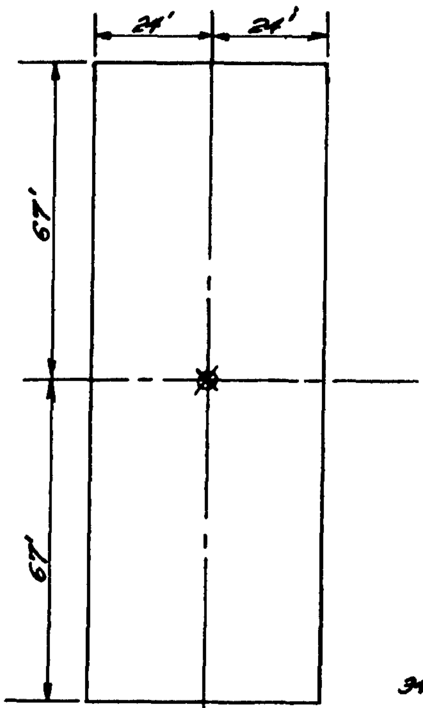
Adjusted contribution, side BD = $0.332(0.199) = 0.066$

5. ④ − ② = $0.066 - 0.060 = 0.006$

6. Shaded area contribution = $0.04\left[0.06 + \frac{1}{2} \times 0.006\right]$

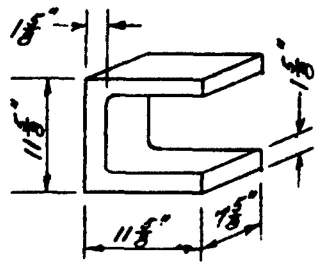
$= \underline{0.00252}$

B. Ground Contribution from Finished Grade



Idealized Plan

Masonry Screen, Computation of Mass Thickness :



Face Area = $10 \times 2 \times 1\frac{5}{8} + 11\frac{5}{8} \times 1\frac{5}{8}$ =

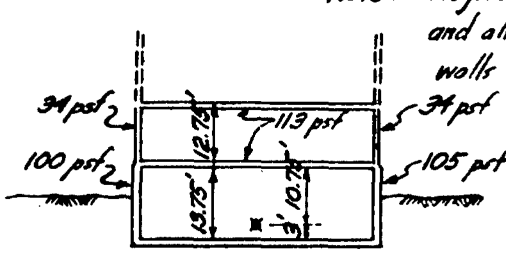
$32.5 + 18.9 = 50.4$ sq. in.

Volume = $50.4 \times 7.625 = 384$ cu. in.

Weight = $\frac{384}{1728} \times 144$, + 2 psf for glass,

= $32 + 2 = 34$ psf.

Note : Neglect entire roof contribution and all ground contribution thru walls of 2d. floor.



Idealized Section

Contribution from Finished Grade, Procedure

1. Consider 1st. Floor at same elevation as outside finished grade and compute, assuming detector is 5' below 1st. floor instead of actual 10.75'
2. Assume entire structure is aboveground and compute contribution.
3. Correct for % exposed basement wall by adding $\frac{3.75}{8.00} \times$ ② to ①
4. Adjust ③ by multiplying it by the ratio $\frac{\text{solid angle for } z = 10.75'}{\text{solid angle for } z = 5.0'}$
5. Adjust ④ by perimeter ratio, since fallout is along the two long sides only. ✓ This step will be included as part of Steps 1 & 2.

1. Area = $48 \times 134 = 6440$ sq. ft.

   $X_w = 34$ psf

   From Chart 4, contribution = 0.053

   To account for 1st. floor thickness, use Chart 1: $0.008 \times 0.053 = 0.00042$

2. For 100 % solid, contribution = 0.03 (105 psf)

   " 0 % " , " = 0.37 (3 psf)

   % Apertures in E. wall = $\frac{10.5 + 8.17}{134} = \frac{18.67}{134} = 0.139$

   Contribution from E. wall = $0.139(0.37)(\underset{\text{Under sill}}{0.2}) + 0.861(0.03)$

   $= 0.0103 + 0.0258 = 0.036$

   Perimeter Ratio, $0.036 \times \frac{134}{\underset{0.368}{2 \times 134 + 2 \times 48}} = 0.013$

   Contribution from W. wall, which has no apertures = 0.03

   Perimeter Ratio, $0.03 \times \frac{134}{2 \times 134 + 2 \times 48} = 0.011$

   Contribution, E. wall + W. wall = $0.013 + 0.011 = 0.024$

3. % Exposed wall = $\frac{3.75}{8.00} = 47$ %

From Step ①, $= 0.00042$

$+ 0.47(0.024) = \underline{0.0112}$

0.0116

4. Since curves are for a detector 5' below 1st. floor, while our detector is 10.75' below 1st. floor, correction will be in the ratio of solid angle with a Z = 7.00' to solid angle with Z = 1.25'.

$$n_1 = \frac{2(7.00)}{134} = 0.104 \qquad e_1 = \frac{48}{134} = 0.36$$

$$w_1 = 0.81$$

$$n_2 = \frac{2(1.25)}{134} = 0.0187 \qquad e_2 = 0.36$$

$$w_2 = 0.966$$

Final Ground Contribution $= \frac{0.81}{0.966} \times 0.0116 = 0.0097$

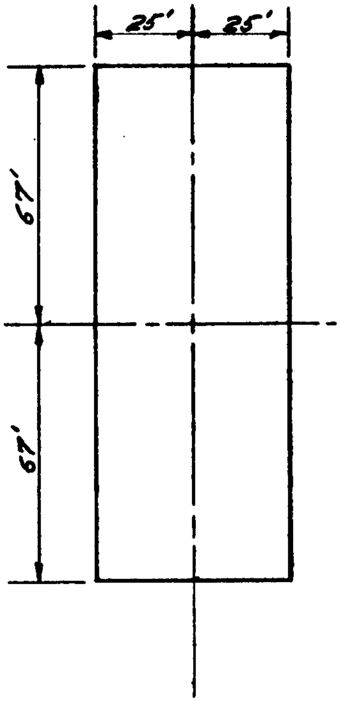
Total Reduction Factor, Areaway plus Finished Grade $= 0.00256 + 0.0097$

$= 0.0123$

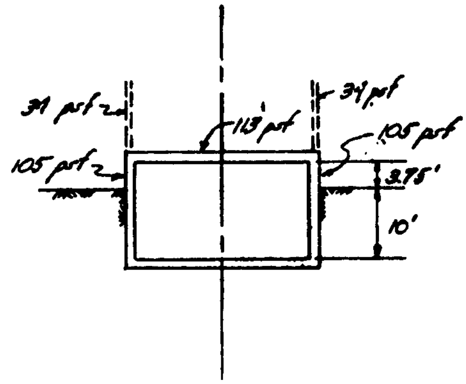
<u>Protection Factor</u> $= \frac{1}{0.0123} = 81$, say $\boxed{80}$

Alternate Computation

In order to obtain an upper bound for value of PF in UCLA Lab Building, consider the following simplified structure, with no apertures or areaways.



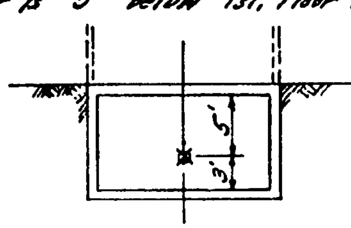
PLAN



SECTION

Note: The 67' dimension is the longitudinal distance from the detector to the fallout boundary on the SW side of the building.

1. Consider 1st. Floor is at same elevation as outside finished grade and compute, assuming detector is 5' below 1st. floor instead of actual 10.75' below.



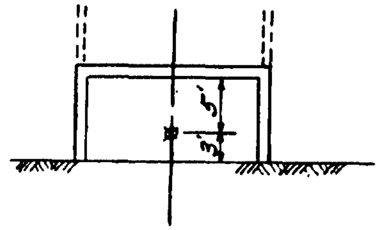
Area = 134 × 50
= 6700 ft.^{2}

From Chart 4, RF = 0.051

From Chart 1, Case 3, RF = 0.008

For fallout on all four sides, RF = 0.051 × 0.008 = 0.00041

2. Assume same structure is above ground and compute contribution.



Note: Neglect contribution thru walls and floor of "2nd." story.

From Chart 3, RF = 0.03

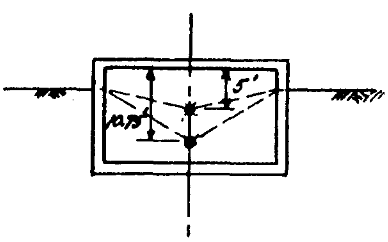
$$\% \text{ exposed} = \frac{3.75}{8.00} = 47\%$$

RF = 0.47 × 0.03 = 0.0141

3. Total RF, for contribution thru all four walls

0.00041 + 0.0141 = 0.0145.

4. Since detector is really 10.75' below 1st. floor instead of 5' below, apply correction. The correction is the ratio of the solid angle subtended at the ground surface by a detector 7 ft. below ground, to the solid angle subtended by a detector 1.25 ft. below ground.



$W = 50$ $\quad Z_1 = 7$ $\quad n_1 = \frac{7}{67} = 0.1044$

$L = 134$ $\quad Z_2 = 1.25$

$\frac{L}{2} = 67$ $\quad n_2 = \frac{1.25}{67} = 0.0187$

Solid Angle Fraction, $\omega_1 = 0.81$

" " " , $\omega_2 = 0.966$

RF for detector 7 ft. below ground (10.75 ft. below 1st. floor)

$$= \frac{0.81}{0.966} \times 0.0145 = 0.838 \times 0.0145 = 0.0121$$

5. Since contribution is only thru the two long walls, apply perimeter ratio correction:

$$RF = \frac{2 \times 134}{2 \times 134 + 2 \times 50} \times 0.0121 = \frac{268}{368} \times 0.0121$$

$$= 0.728 \times 0.0121 = 0.0088$$

6. $PF = \frac{1}{0.0088} = 114$

Try another approach from Step 2:

2. Assume % exposed $= \frac{3.75}{13.75} = 27.3\%$

$$RF = 0.273 \times 0.03 = 0.0082$$

3. Correct RF from Step 1 for solid angle

$$RF = 0.838 \times 0.00041 = 0.000344$$

See Step 4, above

$$RF = 0.0082 + 0.000344 = 0.008544$$

4. Correct for perimeter ratio

$$RF = 0.728 \times 0.008544 = 0.00622$$
$$PF = 1/0.00622 = 161$$

Obviously the PF is quite sensitive to the method of computing the detector height variation in the basement. Very roughly, a factor of $81 \times \frac{161}{114} = 114$ might have resulted if this approach had been used in the actual calculation.

Appendix F

COMPARISONS OF CALCULATIONS AND EXPERIMENTAL DATA

F.1 INTRODUCTION

The purpose of this appendix is to briefly compare some of the experimental data from the Los Angeles experiments with calculations based on the most recent Office of Civil Defense (OCD) Engineering Manual.[1] Calculations are compared directly with experimental data for different phases of the experiment. Total protection factors from both the calculations and the manual are compared, and a general discussion is presented. Estimates used in this appendix are made for the purpose of comparison and explanation of apparent differences in data.

To fully understand the details of the calculations presented here, the reader needs to be thoroughly familiar with the OCD manual and the main body of this report.

F.2 SUMMARY

Estimates of protection factors in existing structures can vary considerably, depending upon the methods used and the input information.

An estimate of the protection factor at a particular location following a simplified fallout-shelter survey guide for architects and engineers[2] has been given in this report. Calculations were made assuming only the mass thicknesses indicated in architectural plans and not considering the actual existence of mechanical equipment in storage areas. The protection factor was estimated to be 80.

An estimate of the protection factor at the same location based on the most recent OCD Engineering Manual,[1] which contains a more detailed analytical method of predicting fallout protection factors, has also been completed. The calculations were made assuming only the mass thicknesses indicated in architectural plans and not considering existence of equipment in storage areas. The protection factor was estimated to be 150.

The effect of the equipment in storage areas on the calculations was next estimated by comparing some individual data points. In addition, estimations of mass thicknesses of individual external and internal walls were made by examining the experimental data. The calculations were then repeated, still following the OCD manual, and new estimations of mass thicknesses and effects of storage areas and mechanical equipment gave a protection factor of 420.

A fourth estimate based on the experimental data gave a protection factor of 680.

An examination of the estimates indicates that at this particular location and structure differences between calculations and experimental data can probably be accounted for by the mass thickness between the source and detector. Sensitiveness of protection-factor calculations to exact mass thickness is demonstrated when a 20% error in estimating the mass thickness of a foot of concrete is proved to result in an error of at least a factor of 2 in radiation contribution.

Protection-factor calculations are usually conservative; this conservatism is understandable when human life is at stake. Most engineers doing these calculations immediately assume minimum mass thickness of materials. Extremely detailed analysis of a structure's protection factor, especially if the building is structurally complicated, would probably produce an estimate that would more closely approximate the experimental data. However, the many variables and unpredicted effects associated with a fallout situation usually do not warrant such an analysis.

Since any simplifications of complex theoretical calculations develop potential error when short cuts are taken to avoid detailed intricate mathematical analysis, survey guides should emphasize their limitations carefully. Perhaps giving more stress to the importance of determining exact mass thickness can lead to improved protection-factor calculations.

F.3 AREAWAY CONTRIBUTION

Position No. 22 (Fig. 3.1) was chosen to compare calculations and experimental data for contribution from the large areaway. The areaway was at the basement-floor level and was 8 ft wide and 54 ft long with an additional 14- by 24-ft area at the south end (see Fig. E.3). The 8-in. concrete wall between the areaway and the basement contained some openings and some thin materials.

Attempts were made to use the OCD manual for calculations of the contribution from the areaway. Because it was difficult to interpolate between the curves in the manual, an alternate method was used. The areaway was divided into segments, and the radiation level at position No. 22 was calculated using Figs. F.1 and 4.1 and assuming the area to be contaminated with Co^{60} to a density of 1 mc/sq ft. The 8-in. concrete wall was assumed to present a mass thickness of 96 lb/sq ft and the internal partitions a mass thickness of 5 lb/sq ft. It was further assumed that no equipment or storage existed in the mechanical-equipment room.

At position No. 22 the radiation level was calculated to be 2.0 mr/hr/mc/sq ft with the greatest contribution (1.5 mr/hr/mc/sq ft) coming from the north 16 ft of the areaway.

Experimental results indicate a contribution of 0.38 mr/hr/mc/sq ft from the large areaway to position No. 22. Since the calculation of dose rate from a limited strip of contamination is a straightforward calculation, the difference of the two results must be due to the mass of material between position No. 22 and the areaway.

The difference between calculated and experimental results is a factor of 5; this factor represents a mass thickness of about 70 lb/sq ft.

There were some storage racks in the mechanical-equipment room which could account for the extra mass. It is also possible that the 16-ft-long panel at the north end of the areaway could have an extra thick coat of plaster both inside and out.

To allow a better estimate of the mass thickness of the walls and the storage area, some individual data points are compared in reference to their location on the floor plan (see Fig. 3.1). Position Nos. 32, 31, and 30 indicated levels of 1.2, 0.82, and 1.4, respectively, from simulated contamination in the areaway. These readings, when related to the physical location of the detector positions, indicate the existence of some material in the center of the room.

Consider also the average reading of position Nos. 10, 11, 21, 22, and 23. The average reading at these positions was 0.33, whereas the reading at position No. 14 was 0.90. The calculated dose rate at position No. 14 coming *only* through the hall doorway opening to the areaway was 0.71. These data indicate that there must have been a considerable amount of material in the mechanical-equipment rooms or that the interior partitions were more massive than had been estimated.

It is also of interest to compare the dose received at several positions from the exposure created when the tubing was placed outside on the ground. With the tubing placed in the rear courtyard, the reading at position No. 32 was about two times more than that at position No. 21. Such an increase was also noted for readings at position Nos. 31 and 27 as compared to position Nos. 22, 23, 24, and 34. However, data from the exposure on the front side of the building

indicate a difference of about a factor of 1.5. Considering that the radiation arriving at these points was already scattered by the external walls, the data indicate a further attenuation by the internal wall of a mass thickness from 7 to 15 lb/sq ft.

Calculation of the unattenuated radiation levels at position Nos. 28 and 29 from contamination from the north 16 ft of the areaway indicates a dose rate of about 16 mr/hr/mc/sq ft. Experimental data at these positions were about one-half this value, indicating a mass thickness in the wall of about 28 lb/sq ft.

If the dose rate at position No. 22 is recalculated from contamination in the areaway, assuming the north 16 ft of the outside wall as presenting a mass thickness of 28 lb/sq ft, the internal walls as presenting a mass thickness of 10 lb/sq ft, and the existing storage in the mechanical-equipment room as presenting a mass thickness of 30 lb/sq ft (a fair assumption), then the contribution is calculated to be 0.6 mr/hr/mc/sq ft, which is within a factor of 2 of experimental data. It is felt that this factor represents reasonable agreement when the inaccuracies of estimating mass thickneses between source and detector are considered.

F.4 WALL-SCATTER CONTRIBUTION

For the comparison of calculations and experimental data taken with the tubing on the ground outside, dosimeter positions in "relatively clean" geometric locations were chosen. These locations were position Nos. 50, 51, 52, and 53. As can be seen in Figs. 1.4 and 3.1 of this report, there was little material between these positions and the exposed basement wall.

Solid-angle fractions and wall-scatter directional-response functions for these positions were found using charts 3 and 5 of the OCD manual. The basement is 13 ft from floor to ceiling; the upper 38 in. of the basement wall is exposed above ground. For a calculation of the solid-angle fractions, a fictitious structure was assumed which was 220 ft in length; its width was equal to twice the distance from the position to the west wall. The directional-response functions were determined and differenced according to the position of the exposed basement wall. The resulting wall-scattered response fractions (G_s) for the structure were 0.060, 0.060, 0.050, and 0.025, respectively, for position Nos. 50, 51, 52, and 53.

Assuming the outside wall to be composed of 8 in. of concrete, which would present a mass thickness of 96 lb/sq ft, the fraction of emergent radiation scattered in the wall (S_w) was 0.73 as determined from chart 7 of the OCD manual. Shape factors (E) were 1.18, 1.13, 1.08, and 1.03, respectively, for position Nos. 50, 51, 52, and 53 as determined from chart 8. The wall was assumed to offer an attenuation factor (R_f) of 0.096 as determined from chart 1 of the OCD manual.

Total reduction factors (RF) for the position (the position number appears in parentheses) in the fictitious structure were found by using the following equation:

$$RF = G_s \times S_w \times E \times R_f$$

These results were RF (50) = 0.0050; RF (51) = 0.0047; RF (52) = 0.0038; and RF (53) = 0.0018.

In the fictitious structure the contamination existed on a smooth plane from the building out to infinity. Experimental data were taken from a strip of simulated contamination 72 ft wide and 220 ft long. In addition, because of the first-floor overhang, tubing was so placed that the effective edge of the contaminated strip was 3 ft from the wall. Since radiation levels from wall-scattered radiation are proportional to the gamma flux impinging on the outside of the wall and because of the limited strip of contamination and its position, the total reduction factors were diminished by a factor of 0.56 (see Figs. F.1 and 4.1). Because the strip was on the west side of the building only, the reduction factors were further diminished by the azimuthal-angle fraction that the west wall presents to each position. The resulting reduction factors were 0.0012, 0.0012, 0.0010, and 0.00051, respectively, for position Nos. 50, 51, 52, and 53.

Assuming a dose rate of 500 mr/hr 3 ft above a contaminated infinite plane of 1 mc/sq ft of Co^{60}, the dose rates from the strip of contamination on the west side of the structure at position Nos. 50, 51, 52, and 53 were 0.60, 0.60, 0.50, and 0.26 mr/hr/mc/sq ft, respectively.

The following table presents positions and calculated and experimental results:

Position number	Calculated, mr/hr/mc/sq ft	Experimental, mr/hr/mc/sq ft
50	0.60	0.32
51	0.60	0.43
52	0.50	0.30
53	0.26	0.16

The experimental data were lower than the calculations by an average factor of 0.62. The existence of the storage area and some material in the vicinity of the positions undoubtedly caused slightly lower readings for the experimental data. As can be seen in Fig. 2.14, the ground in front of the building was generally rough, containing clods of dirt and piles of sand. In addition, the ground started sloping downward 50 to 60 ft in front of the structure. These effects reduced the gamma flux impinging at the exposed basement wall and thus resulted in a lower reading for the experimental data.

Considering the above factors, it is felt that the agreement of calculations and experimental data is excellent.

F.5 TOTAL PROTECTION FACTORS

Protection factors were calculated for position Nos. 22 and 58 by the use of straightforward calculations and the OCD manual.

F.5.1 Calculations

Roof contribution was negligible. Direct radiation from ground and wall scatter and skyshine through the basement ceiling were also negligible. The three contributions to consider then are (1) wall scatter from exposed basement wall, (2) skyshine through exposed basement wall, and (3) contribution from areaways.

Position No. 22 is considered first. The wall-scattered directional-response function was calculated to be 0.060. The azimuthal angle presented by the east wall unobstructed by concrete posts is 115°. Considering the internal walls to present an attenuation factor of 0.8, the wall-scatter contribution from the east is 0.0013:

$$0.060 \times 0.73 \times 1.18 \times 0.096 \times 0.8 \times \frac{115}{360} = 0.0013$$

Assuming the storage area does not exist and that the reduction due to the ground sloping down in front of the building is about 0.5, the wall-scatter contribution from the west is 0.0011:

$$0.060 \times 0.73 \times 1.18 \times 0.096 \times 0.5 \times \frac{155}{360} = 0.0011$$

Skyshine directional-response function is taken from charts 3 and 5 of the OCD manual and is 0.013 for position No. 22. Considering the attenuation of 100 lb/sq ft for skyshine radiation to be 0.055,* the skyshine contribution from the east is 0.00006.

$$0.013 \times 0.27 \times 0.055 \times \frac{115}{360} = 0.00062$$

*Discussions of N. Fitzsimmons, Office of Civil Defense, indicate that the vertical-wall-shielding curve for skyshine radiation should be below case 2 of chart 1 of the OCD manual.

Assuming no storage area the skyshine contribution from the west is 0.0001:

$$0.013 \times 0.27 \times 0.063 \times \frac{155}{360} = 0.000096$$

In Sec. F.3 of this appendix, the large areaway contribution was calculated to be 0.0040 assuming minimum mass in walls and no material in the mechanical-equipment room.

Summarizing the contributions we have:

Wall scatter, east = 0.0013
Wall scatter, west = 0.0011
Skyshine, east = 0.00006
Skyshine, west = 0.0001
Areaway = 0.0040

Total = 0.00656

Protection Factor = 150

Various contributions to position No. 58 were calculated in a similar manner. The internal concrete wall next to position No. 58 is 8 in. thick. The various contributions are summarized below:

Wall scatter, east = 0.00012 $\left(0.060 \times 0.73 \times 1.18 \times 0.096 \times 0.063 \times \frac{135}{360} = 0.00012\right)$

Wall scatter, west = 0.00097 $\left(0.060 \times 0.73 \times 1.18 \times 0.096 \times 0.5 \times \frac{140}{360} = 0.00097\right)$

Skyshine, east = 0.000005 $\left(0.013 \times 0.27 \times 0.06 \times 0.063 \times \frac{135}{360} = 0.000005\right)$

Skyshine, west = 0.000086 $\left(0.013 \times 0.27 \times 0.063 \times \frac{140}{360} = 0.000086\right)$

Areaways = 0.0002

Total = 0.001381

Protection Factor = 720

F.5.2 Experimental Data

An estimation of the protection factors at position Nos. 22 and 58 using the experimental data as guidelines is presented in this section. A slightly different approach is used than that presented in the main body of this report.

During the 4- to 5-month time lag between the writing of the main report and this appendix, subsequently revealed data indicate that the protection-factor results presented in the main body of this report are probably conservative. The skyshine contribution was somewhat overestimated. Information received since the writing of the main report tends to lower the skyshine contribution considerably; therefore the protection-factor estimates should be raised.

The experimental data in milliroentgens per hour per millicurie per square foot are as follows (see also Table 3.2):

	Position No. 22	Position No. 58
West exposure	0.13	0.32
East exposure	0.096	0.014
Areaway exposure	0.38	0.002

The radiation level at the outside of the exposed basement wall from the west ground exposure is estimated to be about 130 mr/hr/mc/sq ft. The level at the wall from contamination beyond the measurement area is entirely from skyshine and is estimated to be 24 mr/hr/mc/sq ft. Wall scatter from contamination beyond the measurement area to the west is then equal to the data times 24/130. For position Nos. 22 and 58, these contributions would be 0.024 and 0.059 mr/hr/mc/sq ft, respectively.

The radiation level at the outside of the exposed basement wall from the east ground exposure is estimated to be about 130 mr/hr/mc/sq ft. The direct radiation level at the wall from contamination in the courtyard beyond the measurement area is estimated to be about 12 mr/hr/mc/sq ft. Skyshine at the wall is about 24 mr/hr/mc/sq ft. Wall scatter from contamination beyond the measurement area to the east is equal to the data times the ratio (24 + 12)/130. For position Nos. 22 and 58, these contributions are 0.027 and 0.0039 mr/hr/mc/sq ft, respectively.

Experimental data cannot be used as guidelines in estimating skyshine contribution. Therefore the OCD manual calculations are substituted for such data.

The various contributions were changed to fractions of the infinite-plane dose and are summarized below:

	Position No. 22	Position No. 58
Wall scatter, east	0.00025	0.000036
Wall scatter, west	0.00031	0.000760
Skyshine, east	0.00006	0.000005
Skyshine, west	0.00010	0.000086
Areaway	0.00076	0.000004
Total	0.00148	0.000891
Protection Factor	680	1100

F.5.3 Comparison

Total protection factors at position No. 58, as estimated by the two methods, are well within a factor of 2 of each other. The small differences are certainly to be expected considering the assumptions and geometries involved.

Estimations for position No. 22, however, involve a factor of about 4.5 difference. The difference is predominantly due to the existence of more mass between the source and detector than the calculations account for, as was pointed out in Sec. F.2.

Let us recalculate the contribution to position No. 22 using mass thicknesses and reduction factors as indicated by experimental data. From Sec. F.2 the areaway contribution was recalculated to be 0.0012. The average of the detector readings in the center hallway for position No. 9 to position No. 45 is exactly one-half of the average for position Nos. 50, 58, and 61 from the west exposure. This fact indicates that the storage area reduced the wall-scatter contribution from the west by a factor of 2. The contribution then would be 0.0006. Considering material in the mechanical-equipment room to have a mass thickness of 30 lb/sq ft and the internal walls to have a mass thickness of 10 lb/sq ft, the wall-scatter contribution from the east would be 0.00044. With these new values the reduction factor would be 0.0024, and the protection factor would be 420. These values would be well within a factor of 2 of those values obtained using experimental data as guidelines.

F.6 DISCUSSION

The difference between calculations and experimental data in these protection-factor estimates can be accounted for by the mass thickness between the source and the observer. The sensitiveness of protection-factor calculations to exact mass thicknesses is evident. A 20% error in estimating the mass thickness of a foot of concrete results in an error of at least a factor of 2 in radiation contribution. Concrete densities can vary considerably.

Protection-factor calculations are usually conservative; this conservatism is understandable when human life is at stake. Most engineers doing calculations of this type immediately assume minimum mass thicknesses of materials. In addition, if there is no relatively direct method of accounting for a complicated shielded situation, a simplified solution is taken which is usually even more conservative.

Extremely detailed analysis of a structure's protection factor would probably result in a much more accurate estimation than a simplified analysis, especially if the building is structurally complicated. Therefore, if protection-factor estimations made by simplified methods, detailed analyses, or based on experimental data are within a factor of 2 or 3, it is felt that this is excellent agreement.

Calculations in this appendix certainly do not represent a detailed analysis. Such an analysis, in which exact mass thicknesses are used, would probably result in an agreement with experimental data much closer than a factor of 2. However, it is felt that for practical applications protection-factor calculations need not be more accurate than a factor of 2. There are many variables and unpredictable effects associated with a fallout situation, and a detailed analysis of the protection factor for a structure is usually not warranted. When these variables are better understood, a more detailed analysis may be desired.

As an example, let us assume that fallout occurred on the UCLA structure, the wind was blowing and a considerable amount of particle pileup occurred at the exposed basement wall and in the areaways. In this case the protection factors may be a factor of 2 or 3 lower than predicted. On the other hand, if fallout occurred when there was no wind, a detailed consideration of ground-roughness effects would increase the prediction.

The importance of accurately considering mass thicknesses was mentioned earlier. In actual existing structures this is sometimes extremely difficult. Here are a few examples from past experience.

A block house was constructed at the Nevada Test Site for shielding studies. Plans called for concrete blocks filled with poured concrete. The contractor actually used cinder blocks instead. This fact was not discovered until the data were analyzed.

A fallout shelter under a house was studied during the Los Angeles experiments. Owner—contractor estimates of its roof thickness varied from 18 to 30 in. After several days of searching, the original plans were found, and they showed a thickness of 24 in. of concrete.

The original architectural drawings of the UCLA structure indicated a shorter areaway by about 8 ft than actually exists.

The police building at Los Angeles was studied during these experiments. Visual inspection of one wall indicated that it was constructed of light material. However, a detailed inspection, experimental data, and an examination of the architectural plans showed that the lower portion was composed of about 12 in. of concrete. Because of this error the local fallout-survey team had estimated the protection factor to be lower by a factor of 8 to 10 than that based on experimental data.

Many other examples of the difficulty of determining exact mass thicknesses could be cited. Most existing buildings contain internal walls, fixtures, storage, and equipment; all these items are difficult to include in an estimate of exact mass thickness for shielding purposes.

Appendix D presents an estimate of the protection factor derived from the simplified method in the fallout-shelter survey guide.[2] Results, following this guide, are somewhat conservative in complicated structures of the type with exposed basement walls. Because of this limitation and because minimum mass thicknesses were considered, the estimates of the protection factor probably were too low.

Shielding technology has advanced rapidly in the last few years. A monograph written by L. Spencer[3] is an excellent advanced theoretical treatment of structural shielding. The OCD survey guides and engineering manuals represent advancements in practical application of the latest shielding technology. However, any simplification of complex theoretical calculations develops potential error when short cuts are taken to save detailed intricate mathematical analysis. It is recommended that survey guides emphasize their limitations where appropriate and give adequate stress to the importance of determining exact mass thicknesses in shielding calculations.

1. Engineering Manual: Design and Review of Structures for Protection from Fallout Gamma Radiation, Office of Civil Defense, revised Oct. 1, 1961.
2. Fallout Shelter Surveys: Guide for Architects and Engineers, Office of Civil and Defense Mobilization, NP-10-2, May 1960.
3. L. Spencer, Structure Shielding Against Fallout Radiation from Nuclear Weapons, *Natl. Bur. Std. (U. S.), Monograph 42.*

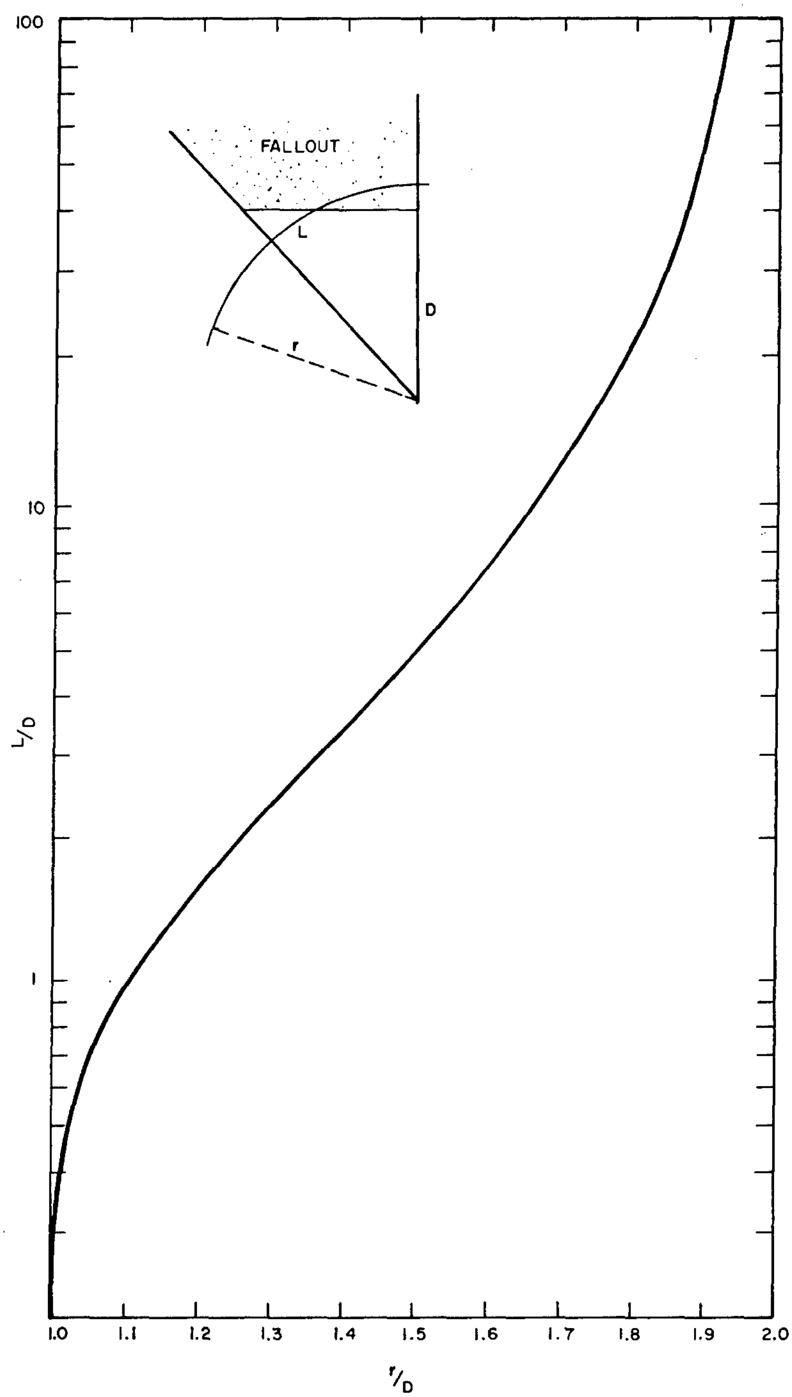


Fig. F.1—Equivalent radial distance (r) to a contaminated area bounded by length of aperture (L) and distance (D) to the area. (Illustrated in the insert.)

CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations Office, the Atomic Energy Commission conducts certain technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

A complete listing of all the studies now underway is impossible in the space available here. However, the following is a list of all reports available from studies that have been completed. All reports listed are available from the Office of Technical Services, Department of Commerce, Washington 25, D. C., at the prices indicated.

CEX-57.1 ($0.75)	The Radiological Assessment and Recovery of Contaminated Areas, Carl F. Miller, September 1960.
CEX-58.1 ($2.75)	Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J. A. Auxier, J. O. Buchanan, C. Eisenhauer, and H. E. Menker, January 1959.
CEX-58.2 ($0.75)	The Scattering of Thermal Radiation into Open Underground Shelters, T. P. Davis, N. D. Miller, T. S. Ely, J. A. Basso, and H. E. Pearse, October 1959.
CEX-58.7 ($0.50)	AEC Group Shelter, AEC Facilities Division, Holmes & Narver, Inc., June 1960.
CEX-58.8 ($1.00)	Comparative Nuclear Effects of Biomedical Interest, Clayton S. White, I. Gerald Bowen, Donald R. Richmond, and Robert L. Corsbie, January 1961.
CEX-58.9 ($1.25)	A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves, I. Gerald Bowen, Ray W. Albright, E. Royce Fletcher, and Clayton S. White, June 1961.
CEX-59.1 ($0.60)	An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, J. F. Batter, Jr., A. L. Kaplan, and E. T. Clarke, January 1960.
CEX-59.4 ($1.25)	Aerial Radiological Monitoring System. I. Theoretical Analysis, Design, and Operation of a Revised System, R. F. Merian, J. G. Lackey, and J. E. Hand, February 1961.
CEX-59.4 (Pt.II) ($1.50)	Aerial Radiological Monitoring System. Part II. Performance, Calibration, and Operational Check-out of the EG&G Arms-II Revised System, J. E. Hand, R. B. Guillou, and H. M. Borella, Oct. 1, 1962.
CEX-59.7C ($0.50)	Methods and Techniques of Fallout Studies Using a Particulate Simulant, William Lee and Henry Borella, February 1962.
CEX-59.13 ($0.50)	Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, T. D. Strickler and J. A. Auxier, April 1960.
CEX-59.14 ($1.75)	Determinations of Aerodynamic-drag Parameters of Small Irregular Objects by Means of Drop Tests, E. P. Fletcher, R. W. Albright, V. C. Goldizen, and I. G. Bowen, October 1961.
CEX-60.1 ($1.75)	Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center, H. Borella, Z. Burson, and J. Jacovitch, February 1961.
CEX-60.3 ($1.50)	Extended- and Point-source Radiometric Program, F. J. Davis and P. W. Reinhardt, August 1962.
CEX-60.6 ($1.00)	Experimental Evaluation of the Radiation Protection Provided by an Earth-covered Shelter, Z. Burson and H. Borella, February 1962.
CEX-62.01 ($0.50)	Technical Concept—Operation Bren, J. A. Auxier, F. W. Sanders, F. F. Haywood, J. H. Thorngate, and J. S. Cheka, January 1962.
CEX-62.02 ($2.25)	Operation Plan and Hazards Report—Operation Bren, F. W. Sanders, F. F. Haywood, M. I. Lundin, L. W. Gilley, J. S. Cheka, and D. R. Ward, April 1962.
CEX-62.2 ($1.00)	Nuclear Bomb Effects Computer (Including Slide-rule Design and Curve Fits for Weapons Effects), E. Royce Fletcher, Ray W. Albright, Robert F. D. Perret, Mary E. Franklin, I. Gerald Bowen, and Clayton S. White, Feb. 15, 1963.